Course Manual

Directed Assistance Module 9

Special Studies in a Surface Water Treatment Plant

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Background Information

Special Studies in the Water Treatment Plant

Studies are performed in a surface water treatment plant almost daily. There is nothing "special" about them, in that they are very routine for water operators.

Table 1 compares these routine studies and the special studies.

In Table 1, we see that there is a lot of information that water operators routinely collect, record, and act upon. These are "studies" even if the information is collected with on-line instruments and shown on a Supervisory Control and Data Acquisition (SCADA) system display screen. This is because, as operators, we not only evaluate the information, we also decide if the values and/or trends are good, marginal, or bad. Of course, should the results be marginal or bad, we will consider doing something about it.

Table 1: Routine Monitoring, Routine Actions, and Special Studies

<table>
<tr><th>Routine monitoring</th><th>Typical Routine Actions</th><th>Typical Special Studies</th></tr>
<tr><td>Combined Filter Effluent (CFE) turbidity</td><td>• Record and evaluate desirability of the reading
• Consider backwashing filters
• Consider change in treatment strategy</td><td rowspan="5">• Produce a more complete description of the design and operational status of treatment units and essential process management equipment
• Determine the cause of an undesirable reading by experimentation or other evaluation
• Determine the best treatment strategy to improve water quality or return water quality parameters to acceptable limits by experimentation or other evaluation</td></tr>
<tr><td>Disinfection zone residual, pH, temp</td><td>• Record and calculate the inactivation ratio
• Evaluate adequacy of readings and inactivation ratio (IR)
• Consider change in treatment strategy</td></tr>
<tr><td>Entry Point (EP) residual</td><td>• Record and evaluate adequacy of the reading
• Adjust disinfectant feed up or down</td></tr>
<tr><td>Flow rates</td><td>• Record and evaluate chemical feed rates relative to flow
• Adjust chemical feed rates to match flow</td></tr>
<tr><td>Individual Filter Effluent (IFE) turbidity</td><td>• Record and evaluate the desirability of the reading
• Consider backwashing a filter
• Continue operating with no change</td></tr>
</table>

Raw water turbidity, pH, alkalinity	• Record and evaluate the adequacy of the treatment strategy to treat the water supply • Consider chemical treatment strategy change	
Settled water turbidity	• Record and evaluate the desirability of the reading • Consider change in treatment strategy	

Special studies: Address a single specific issue: Unlike routine studies, special ones:

- **Use principles of trouble-shooting:** Each variable is considered, and only one is changed at a time. When a change is made for testing, it is re-set to baseline before the next test.
- **Use scientific methods:** An initial hypothesis—or "guess"—is used to design an experiment, resulting in recommended changes and follow up actions. Special studies have a timeline, unlike routine studies.
- **Result in an action plan:** The special study has an endpoint, where the results are reviewed in detail, followed by fact-based decision making. The action plan might be specific changes, or it might be 'do nothing,' 'get more training,' 'request funding,' or even 'design a new special study.' But a special study will always include recommended actions.

The term "**special studies**" was created to describe:

- Studies used to evaluate the status of SWTP treatment units and essential process management equipment beyond the normal preventive maintenance checks,
- Studies that help operators find out why the treated water quality is changing, or
- Studies that evaluate alternative adjustments in the treatment strategy to resolve a problem or to improve a treatment process.

As such, special studies can have an impact on regulatory compliance, the cost-effectiveness of treatment, and the satisfaction of your customers in the product that you provide.

Some of your reactions to the water quality at different phases of treatment are almost automatic: they are based on the intelligent application of past experience or education. These are, most often, very effective at producing good water. There are times, however, when we make the usual adjustments and the results are not what we expect. In these cases, we can:

- Check to see if we have made the adjustment precisely as we wanted to,
- Check to see if all the chemical feeders and pumps are working correctly, and
- Check to ensure that all our instruments are working and reporting correctly.

What if none of those are a problem? What then? Well, we could do any of the following:

- Call the chemical vendor (not a bad idea),
- Speak with the chief operator,
- Call a consulting engineer,
- Wait for things to go back to normal,
- **Perform a special study** to evaluate a problem or condition.

We highly recommend the special studies option, but performing a special study requires following a reliable, well-defined process.

Choosing a Special Study:

When a treatment unit begins to perform less efficiently or catastrophically fails, we will probably need to perform a special study. Before we begin, we will need to decide what we want the special study to produce:

Performance status

- **Do we need to make sure a treatment unit or the process management equipment is functioning as it should?** This evaluation would be above and beyond the normal status checks performed for preventive maintenance.

Why?

- **Do we want to find out why something is happening?** We have an idea about what is going on in a treatment process, but we need to confirm what is going on so that additional actions may be taken.

How?

- **Do we want to find adjustments we can make to the treatment process to produce better water?** We have an urgent need to improve treatment to return to compliance or to avoid going out of compliance; or we have a long-term goal of refining our treatment processes.

Before beginning a special study, we definitely need to confirm the operational status of all critical equipment. In a perfect world, we would also want to know why something is happening as well as what we are going to do about it every time a situation needing attention arises. But sometimes there just isn't enough time and we bypass the "why?" and go straight into the "how can we improve?" mode.

Once we have found out what we can do about a situation, perhaps we can go back and find out why things happened the way they did. Also, sometimes when we find out what we can do to improve the water quality, the "why?" becomes obvious.

The "Performance-Status" Special Study:

As a point of reference, there are several "information gathering" studies that the Texas Optimization Program (TOP) performs on a routine basis during more comprehensive plant evaluations. These studies collect information that is not gathered by the plant operators' normal monitoring and reporting routine; or they assemble routinely collected information in a way that reveals something about the treatment strategy. These are performance-status special studies. They do not employ the scientific method (which will be discussed later) and the procedures for conducting these studies are pretty routine for the TOP.

The performance-status studies produce information that can be compared to design documents, standard operating procedures (SOPs), operations manuals, etc., to determine whether or not the equipment is well maintained and/or is performing properly. Many of these studies focus on the filter condition, as the filters are the last particle removal unit in the plant. The performance status studies can be performed to lay the groundwork or feed into the "How can we improve?" special studies. The TOP's comprehensive performance status special studies include:[1]

- Maximum daily turbidity profiles for the raw water, settled water, filtered water, and finished water for a 12-month period;
- Comparison of on-line turbidimeter, flow meter, and disinfectant residual monitor readings to SCADA records and displays;
- Timed settling tests to determine if the coagulation and flocculation processes are forming a floc that will settle effectively;
- Flow splitting measurements to ensure parallel units that are supposed to receive proportional flows are actually receiving the flows intended;
- Filter run turbidity profiles (from being placed into service following a backwash to being taken off-line for the subsequent backwash) using IFE turbidity data collected at one minute intervals;
- Post-backwash turbidity profiles using IFE turbidity data collected at one minute intervals;
- Filter bed probes to determine the depth of the filter bed and the levelness of the gravel or media support system across the filter (these measurements are compared to the approved design documents);
- Excavations of the filter bed to determine the condition of the media and the structure of the media layers (these findings are compared to the approved design documents);
- Washing of media samples in mild acids or bases to determine if the media is covered with a chemical or biological coating;
- Media sieve tests to determine the effective size and uniformity coefficient of the media layers (these measurements are compared to the approved design documents);
- Profiles of unit performance versus plant flow; and

[1] This is not intended to be an exhaustive list.

- Other comparisons.

The easiest way to demonstrate these special studies is to show the information they produce and describe the way that the information is gathered. However, please be aware that these examples often show an extreme degree of deviation from the expected design and operational elements for the units evaluated. These examples were chosen for this very reason: they clearly illustrate how easy it is to assemble design and process management information.

Examples of Performance Status Special Studies

1. Maximum daily turbidity profiles for the raw water, settled water, filtered water, and finished water:

   Figure 1 (see the next page) shows a commonly used TOP tool used to evaluate the relative performance of the treatment units in a plant. These charts, assembled during an actual plant evaluation by the TOP, display the maximum daily turbidity readings for the raw water, the settled water, the individual filter effluent (IFE), and the combined filter effluent (CFE). Using this type of figure, the operator can compare the function of the coagulation, flocculation and settling processes against the raw water turbidity trend; the performance of the filters can then be compared by the raw water turbidity and the settled water turbidity; and the performance of the complete bank of filters can be compared to the raw water turbidity, the settled water turbidity, and the performance of the least effectively performing filter.

   In Figure 1, please note the treatment plant was off-line for one entire month. However, it can be seen that the raw water turbidity trend and the settled water turbidity trends follow the same general pattern and the settled water turbidity is often, for months at a time, below 1.0 NTU. However, the performance of the filters, both at the IFE and CFE monitoring points fluctuate independently of the raw and settled water turbidity trends. Also note that the maximum daily IFE turbidity fluctuates between 0.1 to 0.9 NTU. These points of information imply:

   - The coagulation, flocculation, and sedimentation processes are very effective at removing raw water turbidity. The floc formed settles well.
   - The filters to not perform in a consistently efficient level of performance. This type of chart does not indicate "why" the filters are nor performing efficiently only that they are not. The reason(s) for the failure could be because:
     - The filters are not operated effectively (possibly, due to many different reasons).
     - The particles in the settled water are not electrochemically conditioned to be captured by the filters.
     - There are particles that precipitate (iron, manganese, afterfloc, etc.) after the water passes through the filter media and before the sample collection point for the on-line turbidimeters.
   - The bottom line is that the operators at this plant should evaluate their treatment processes to determine the cause of the inefficient filter performance and, if possible, correct the problem.

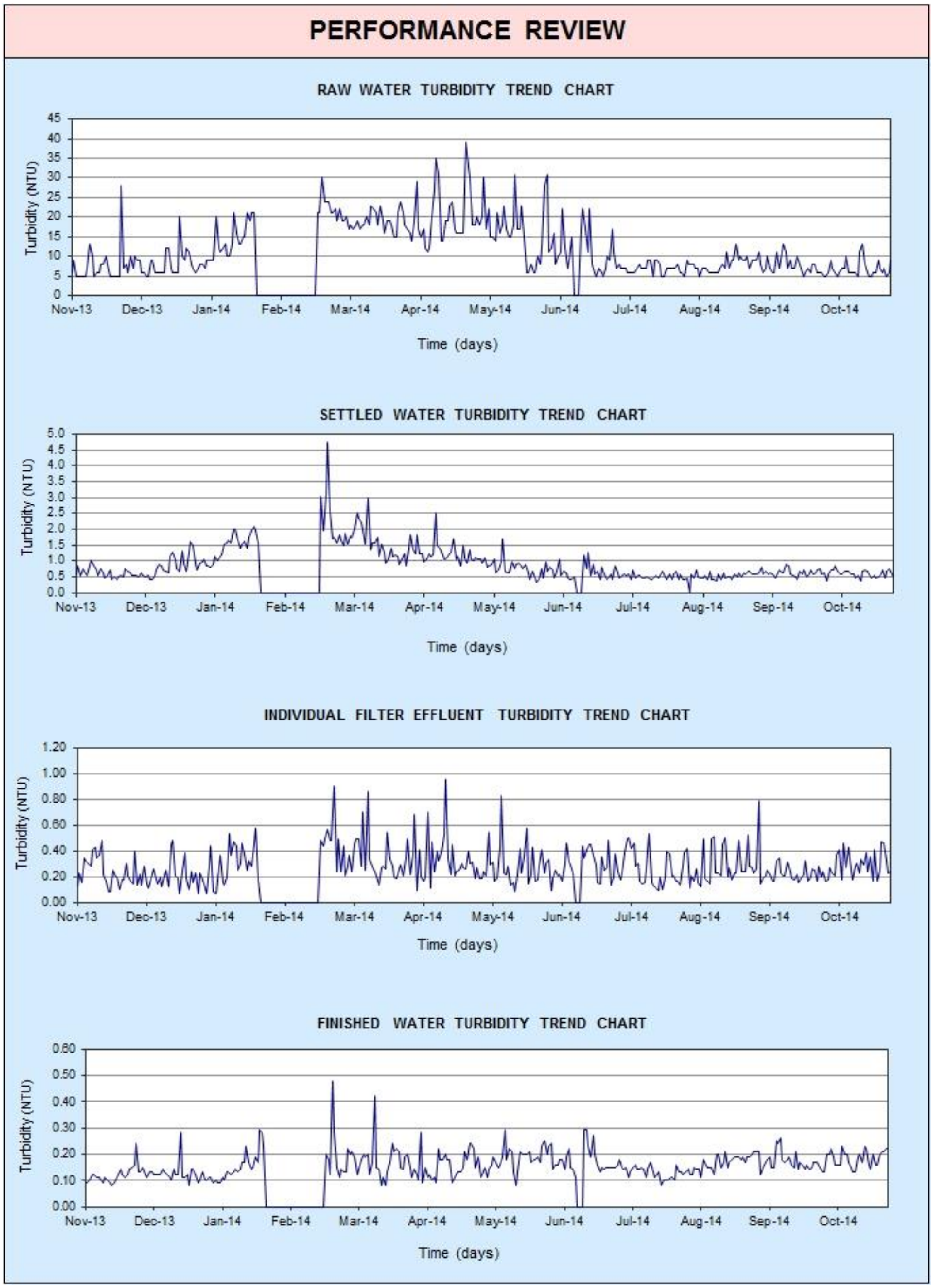


Figure 1: Performance Review - Comparison of Turbidity Trends

2. Comparison of on-line turbidimeter, flow meter, and disinfectant residual monitor readings to SCADA records and displays:

The TOP has encountered several situations where the on-line monitoring equipment reflected water flows and water quality that was different from the information recorded by the SCADA system receiving the information from the on-line monitors. In more than one instance, the IFE turbidity from one filter was recorded as the IFE turbidity for a different filter. Additionally, on-line instruments can be capped so that a reading above, or below a certain level is never sent. Also, the SCADA system can be capped as to the maximum or minimum readings that it will record. Figure 2 shows an example of one situation where the TOP downloaded the electronic record from the on-line turbidimeter for a filter and compared it to the maximum daily turbidity values reported on the SWMORs for that filter. The turbidimeter calibration record showed that the turbidimeter was reading accurately. The values reported on the SWMOR were confirmed to be consistent with the IFE turbidity recorded by the SCADA system. It is apparent that the SCADA record did not correctly reflect the filtered water turbidity. (It was discovered, later, that the operating company's data manager was modifying the SCADA record without the on-site operators being aware of it.)

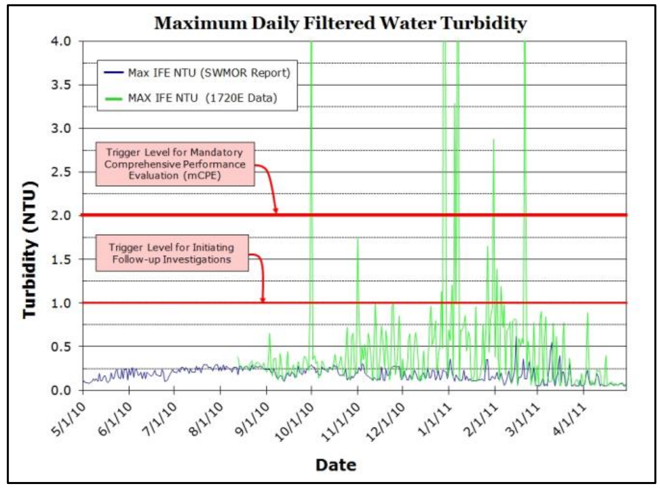


Figure 2: Comparison of On-line Turbidimeter Record versus the SCADA Record

Another way that the SCADA system can be configured incorrectly is to have an upper limit assigned, even though it is recording correctly up to that limit. Figure 3 shows another example of an evaluation the TOP performed. Notice that the TCEQ turbidimeter and the plant turbidimeter readings are very similar. The SCADA system turbidity record follows the same trend pattern until the turbidity reaches 2.0 NTU.

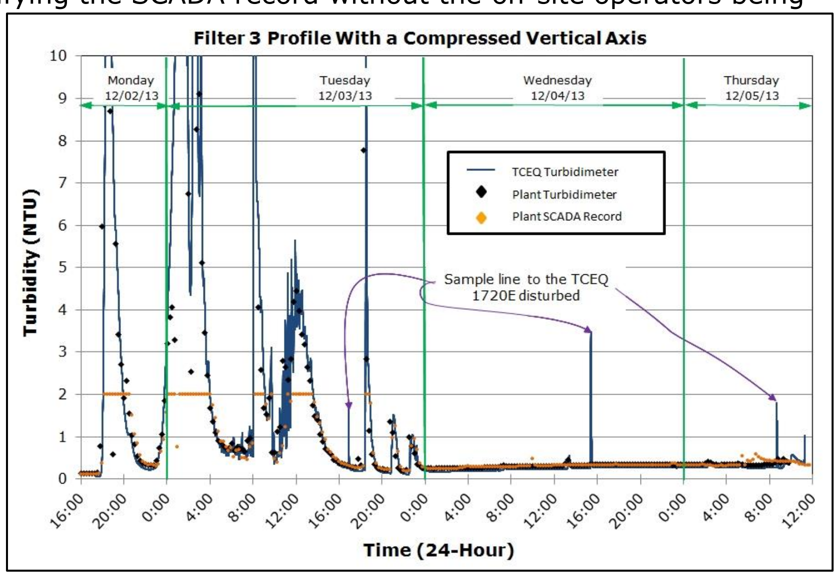


Figure 3: Comparison of On-Line Turbidity versus the SCADA Record -2

Figure 4 shows an example where the SCADA system always recorded IFE turbidity values of only a fraction of what was actually measured by the on-line turbidimeter. Care should be taken that the SCADA system knows what the 4 to 20 milliamp signal from an on-line instrument's sending unit means. If the sending unit says that the range for 4 to 20 means 0 to 10 NTU and the SCADA system interprets it as 0 to 1.0 NTU, the SCADA record will always be wrong.

Problems with the SCADA system may stem from the failure of the operator or the SCADA contractor to communicate effectively or failure to keep the SCADA system up to date. Additionally, the phenomena shown in Figures 2, 3, and 4 can be found for other on-line instruments as well.

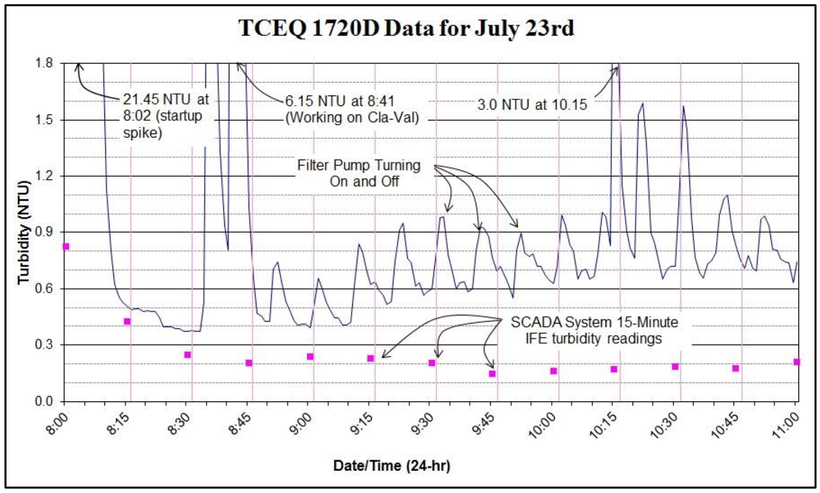


Figure 4: Comparison of the On-line Turbidimeter versus the SCADA Record - 3

3. Timed settling tests:

The five-minute settling test is a commonly used process control parameter for solids-contact clarifiers. Timed settling tests can also be used for conventional sedimentation basins. Figure 5 shows two series of settling tests run on different days. The picture on the left shows "one-hour" settling tests run by operators at a plant undergoing a TOP evaluation. The picture on the right shows a settling test conducted by the TOP two days later, after assisting the operators to select a more effective coagulant-coagulant aid combination (using jar testing) for their solids contact clarifiers. On the left, the floc had settled to about the 40% level after one hour. On the right, the floc had settled to 20% after only ten minutes. These tests show that on Monday, the floc was very light and did not settle well. On Wednesday, the floc was much denser and would settle faster. (Because the alternate coagulant dose and coagulant aid had only been used for a few hours, the complete conversion to the alternate treatment was not yet complete.)

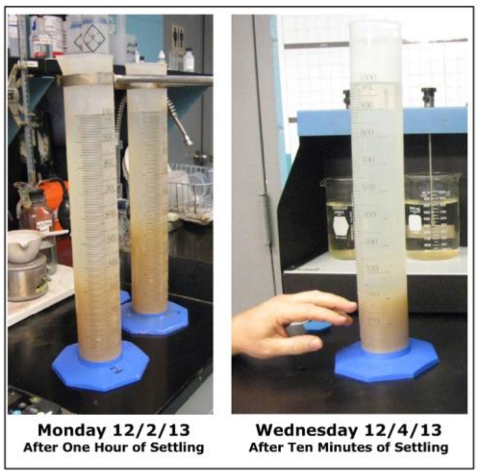


Figure 5: Timed Settling Tests

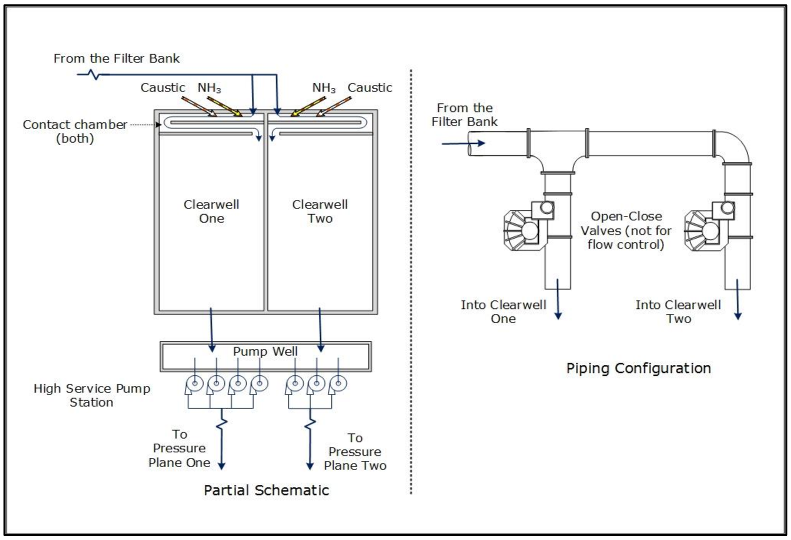
The timed settling test can be tailored to the needs of most plants based on the operators' preferences.

4. Flow splitting evaluations:

Many plants have flow splitting mechanisms that are based on "equivalent piping." When the piping is actually equivalent, the principle is sound and the flow will be equally split between units of equal size and equivalent piping. However, in most instances, another factor comes into play: velocity head. Velocity head is a term that we can think of as "momentum." Two situations the TOP encountered where the effects of momentum of the water illustrate this principle quite well. In both situations, the momentum of the water overcame the "equivalent piping" of the engineering design, resulting in unequal flow to equivalently sized units.

In the first example, a plant with duplicate units of every kind, the filtered water was piped to two contact chambers followed by two clearwells. This example is shown in Figure 6, which shows the water transferred from the filter bank to a pair of contact chambers and clearwells. Both the contact chambers and clearwells were identically sized. On the left hand side of Figure 6, one can see that the flow enters the contact chambers from equally sized pipes, follows the chamber and empties into the clearwells. On the right hand side, two open-closed valves are shown on the filtered water transfer lines serving both of the clearwells. The flow from the clearwells is transferred to a common pump well at the high service pump station, and is then pumped into two different pressure planes.

The TOP suspected that the piping did not actually split the flow equally between the equivalent units because the valves on the inlet lines were not flow control valves. They simply opened or closed, and normally operated in the fully open position. Therefore, the TOP reviewed the water level records for both clearwells. For Clearwell 2, the water level was always at least one foot higher and at the time of the evaluation, the level in Clearwell 2 was 2.15-feet higher than the level in Clearwell 1. The only way for this to happen, if each of the clearwells were the same size, was if the momentum of the water in the transfer pipe carried the water past the pipe leading to Clearwell 1 and fed it into Clearwell 2.



Notice the chemical feed points at the head of the contact chambers on the right side of Figure 6. The chemical feeds were adjusted based on the premise that the flow into each clearwell was the same. Consequently, the ammonia injection resulted in an overfeed in Clearwell 1, and a higher free ammonia level in the transfer line from Clearwell 1 to the Pump Well than was shown to be in the transfer line from Clearwell 2.

Further, the pH of the water in the transfer line from Clearwell 1 was higher than the pH in the transfer line from Clearwell 2. In other words, there were several indicators that the flow into Clearwell 1 and Clearwell 2 were not equal.

The second example occurred at a plant where a splitter box was used to distribute flow between filters that were assumed to receive the same settled water flow. Figure 7 shows the plant schematic for a plant with ten filters. The middle part of Figure 7 shows the configuration of the settled water flow to a splitter box serving 10 filters. The splitter box feeds the filters through equal level pipe weirs, each serving one filter.

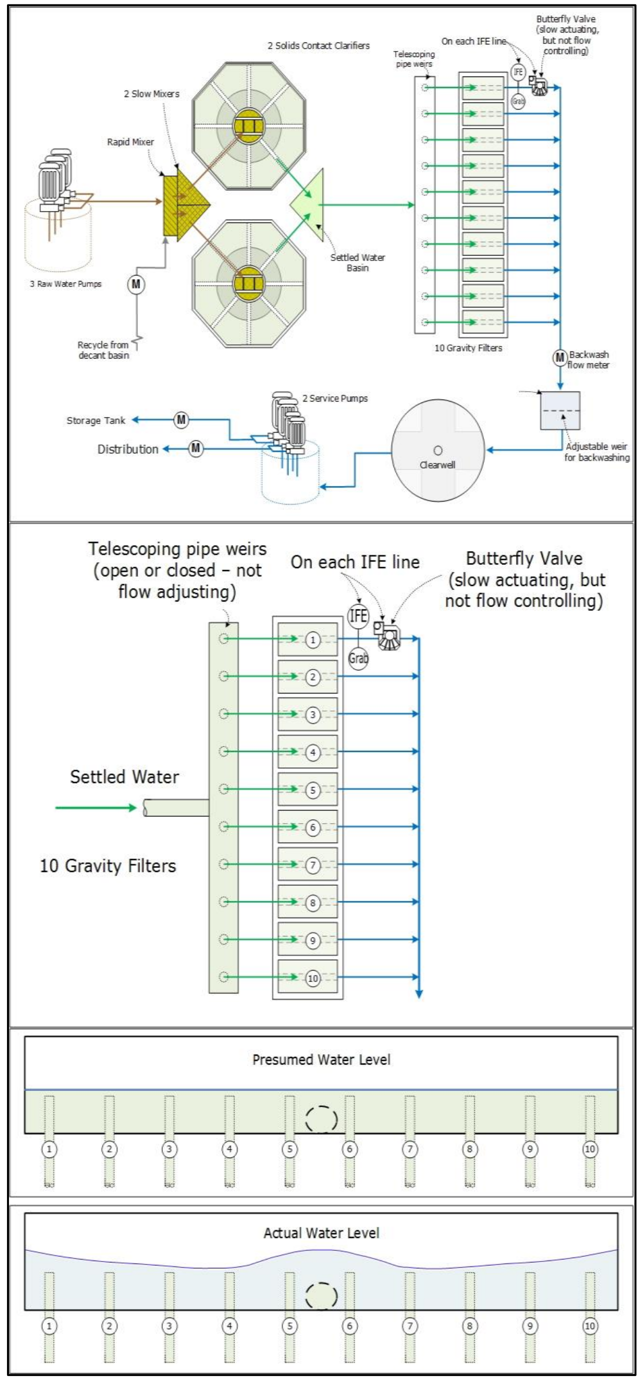


Figure 7: Flow Splitting - Example 2

The design assumption is that the water level in the splitter box should be the same from end to end and the lip of the pipe weirs are all at the same height, so all the filters will receive the same proportionate flow. However, this assumption is false. First, the box inlet is at the center and the incoming water has to change directions. This results in a rise in the water level at the center of the splitter box. Further, the momentum of the water flowing to each end of the box causes a higher surface level at the ends of the box than at the pipe weirs between the inlet and the end. Since the flow through pipe weirs is based on the height of the water above the lip of the pipe weir, the higher water level at Filter 1 and Filter 10 results in their receiving more flow than the other filters. The TOP measured rise rate in Filters 1, 4, and 5; by closing the effluent valves and seeing how long it took for the water in the filter box to rise six inches. The results were:

- Filter 1 – 43 seconds, for a loading rate of 5.23 gpm/ft^2
- Filter 4 – 60 seconds, for a loading rate of 3.75 gpm/ft^2
- Filter 5 – 52 seconds, for a loading rate of 4.33 gpm/ft^2

Clearly, the flow is not evenly split between the filters. The operators confirmed that Filters 1 and 10 required more backwashing than any of the other filters, evidently because they were receiving more water than the other filters.

5. Filter run turbidity profiles:

Figure 8 shows an idealized filter run profile with turbidity levels recorded at 1-minute intervals. Deviations from this type of profile indicate filter performance issues. Each change in IFE turbidity is because of an event that changes the quality of the water reaching the turbidimeter. The events on the idealized chart are presented in Table 2. Notice that the idealized chart shows that the IFE turbidity remains fairly constant after reaching the fully ripened condition and this continues until the beginning of breakthrough which will trigger another backwash. Deviations from this idealized profile normally indicate settled water turbidity issues, filter loading rate issues, or other filter issues. For example, Figure 9 shows a filter run turbidity profile that is disrupted by the backwashing of another filter. It is easy to see that the filter run turbidity profiles are not at all similar to the idealized filter run profile. The up and down turbidity trending for both filters show:

- The filter loading rate is going up and down. This was confirmed to be true because the plant cycled on and off and the plant flow rate was not adjusted when one of the three filters was taken off line for backwashing.
- The filters exhibit periodic turbidity breakthrough, at least once following the backwash of another filter, and several other times for unknown reasons. (There are reasons for every filtered water turbidity change, but the TOP did not uncover those reasons during this evaluation.)

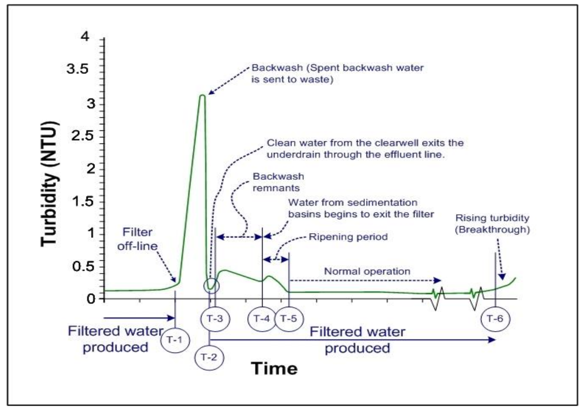


Figure 8: Filter run turbidity profile

Table 2: Times for Idealized Filter Run Events

Time	Event
T-1	The end of a filter run and the beginning of the filter backwash.
T-2	The end of the backwash.
T-3	The time when backwash water that actually entered the media bed during the last seconds of backwash begins to exit the filter.
T-4	The second bump in the post backwash spike, occurs when the first water from the sedimentation basin finally begins to exit the filter effluent line.
T-5	The end of the ripening process and the beginning of normal filter operation at or below the IFE turbidity level observed before the backwash.
T-6	The beginning of filter breakthrough which will trigger another backwash and run cycle.

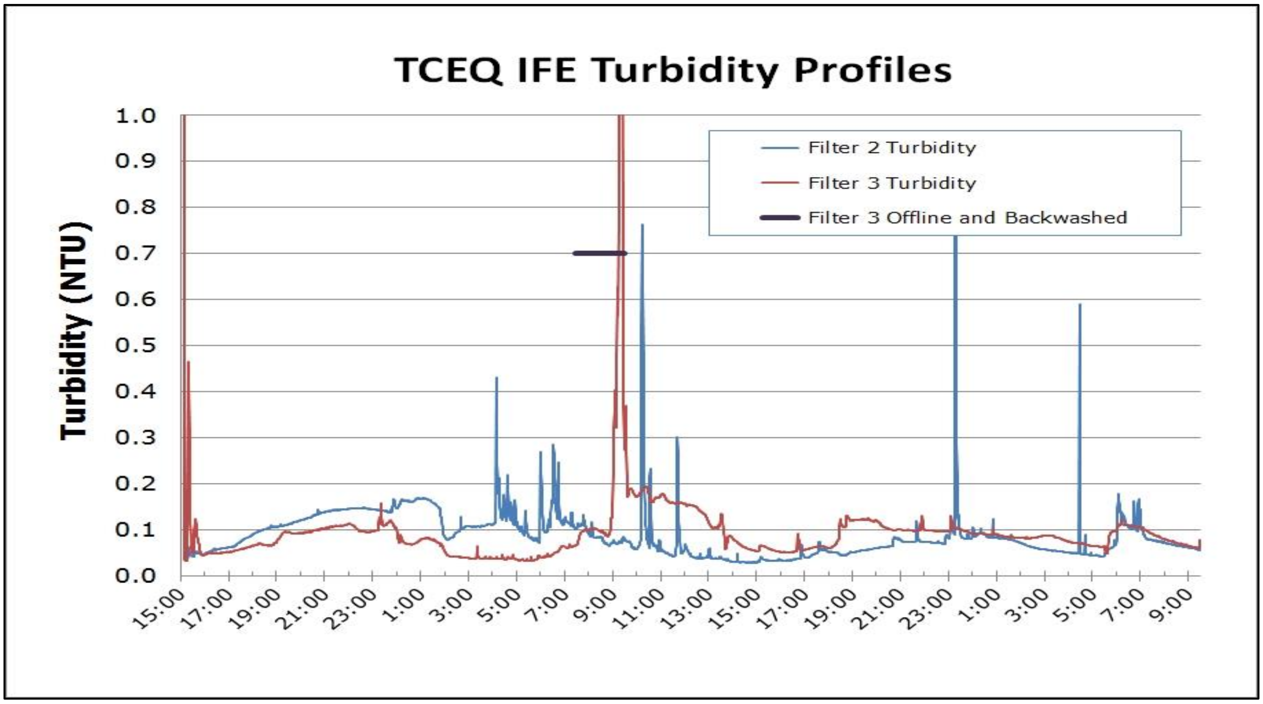


Figure 9: Filter Run Profiles for Two Filters

6. Post-backwash turbidity profiles:

Figure 10, above shows an atypical post-backwash turbidity profile using data collected at 1-minute intervals. These data were collected by the TOP during a comprehensive performance evaluation at a surface water treatment plant in Texas. Note that that the T-1 through T-5 time references are the same as those in Figure 1. Table 3 shows how the TOP interpreted the data.

The major point to be learned from this example is that constructing these profiles reveals a lot about the function of the filter and also indicates areas worth additional evaluation.

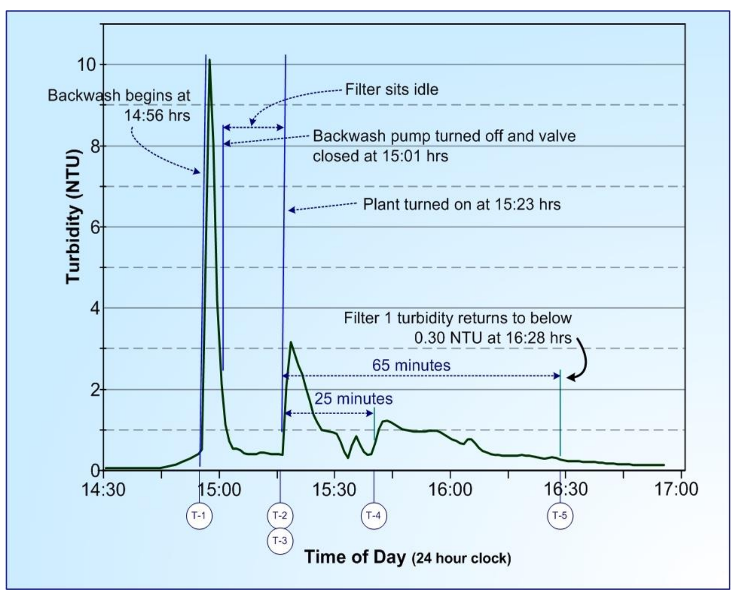


Figure 10: Atypical Post-Backwash Turbidity Profile

Table 3: Issues Revealed by a Post-Backwash Turbidity Profile

Issues Revealed by the Post-Backwash Turbidity Profile	
1	Fact: The post-backwash turbidity spike peaks at above 3.0 NTU and the spike remained above 2.0 NTU for about seven minutes.
2	Fact: If the spike were to be further prolonged, the system would be at risk for having a confirmed reading above 2.0 NTU.
3	Fact: Though there was a brief period of lower turbidities, the filter continued to produce water above 1.0 from about 15:02 hours to around 15:57 hours. Even with the intermittent period of reduced turbidity, the system does have a confirmed IFE turbidity reading above 1.0 NTU.
4	Fact: The five minutes of backwash flow does not appear to produce the desired results. Clearly, when the backwash water is turned off, the 3.0 NTU spike contains too many remaining particles to call the filter "clean".
5	Conjecture: The very long ripening period suggests that the operator might want to consider addition of a filter aid immediately after filter startup to shorten the ripening period.
6	Conjecture: The lack of the short period when clean clearwell water in the underdrain passes through the effluent line suggests that there is a leaking valve, and this cleaner water is leaving the filter during the 22 minutes while it is supposed to be idle. While this is conjecture, this type of finding in a filter profile should provoke one or more special studies and/or a maintenance activity to see if this problem can be eliminated.

7. Filter bed probes:

Evaluating the condition of a filter bed is one of the most important special studies that an operator can form. On the left side of Figure 11 is a diagram showing filter media depth measurements. On the right side of Figure 11 is a disassembled probe.

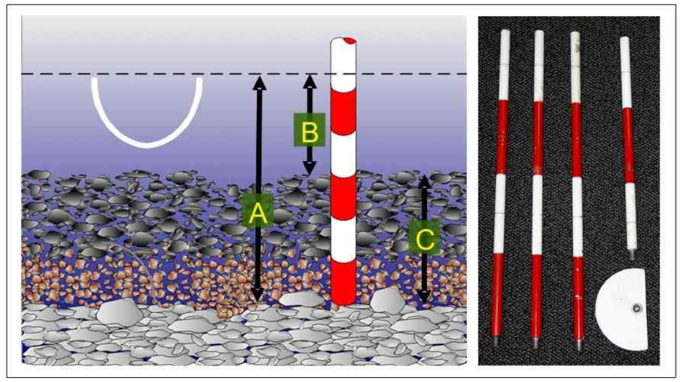


Figure 11: Filter Probe Measurements

In Figure 11, the "A" measurement represents the distance between a constant level reference point to the media support system (in this case, gravel). The reference point used is the top of the backwash trough. The "C" measurement is the depth of the media at the location the probe is inserted. The "B" measurement is the distance from the reference to the top of the media. The A and C measurements are what we want, but, since A = B + C, all three are shown. Depending on the height of the trough above the surface of the gravel, A may have to be measured by adding the B and C measurements.

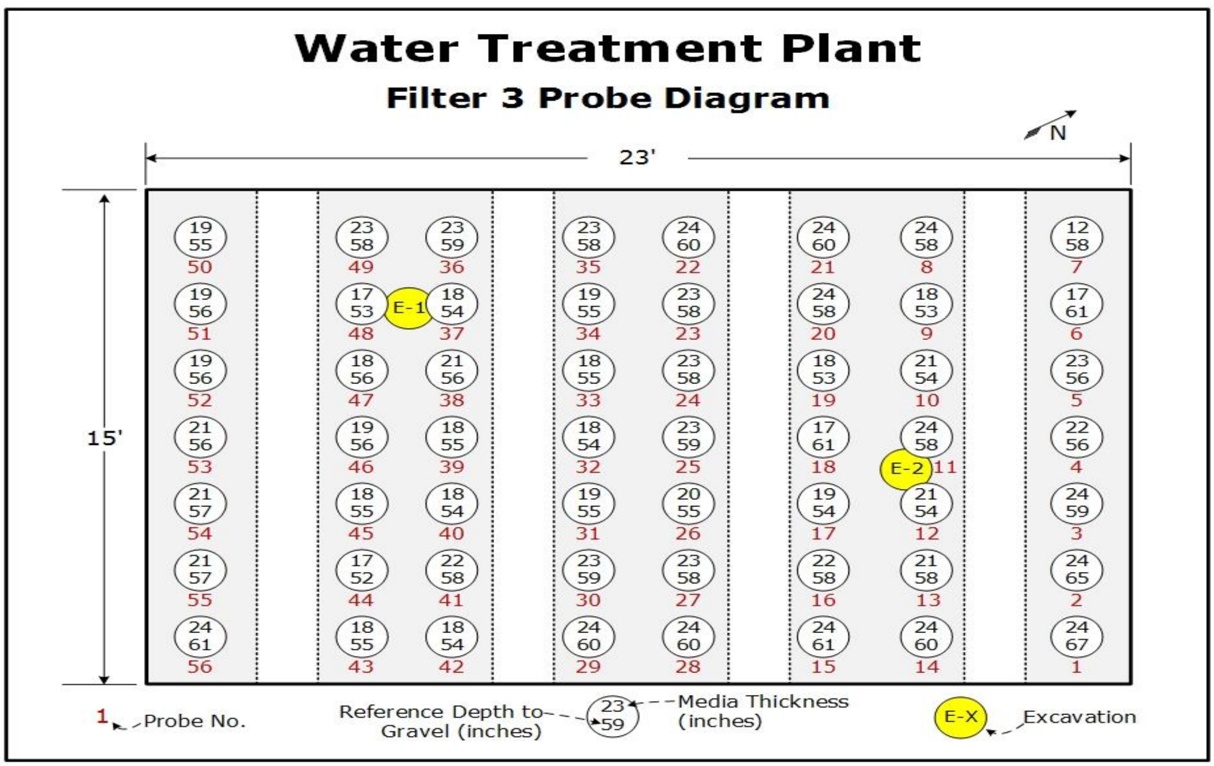


Figure 12: Filter Probe Diagram

Figure 12 shows a plan view of the probing project the TOP performed for a filter with performance issues. Figure 12 shows the depth of the media layer, the reference depth for each probe. There are so many data points that the TOP assembled the information in Table 4.

The table contains averages, maximums, minimums, and differences between maximums and minimums for the media depth, the reference depth to the gravel, and the reference depth to the surface to the media. The table shows that the media depth varied by 12 inches, the level of the gravel varied by 15 inches, and the height of the media surface varied by 13 inches.

Since the expected difference between the maximum and minimum for each of these measurements is 3 inches, this shows why the filter was not performing well.

Table 4: Display of Filter Probe Measurements and Calculations

Location	Media Depth (Inches)	Reference to the Gravel Surface (inches)	Reference to the Media Surface (inches)	Location	Media Depth (Inches)	Reference to the Gravel Surface (inches)	Reference to the Media Surface (inches)
1	24	67	43	29	24	60	36
2	24	65	41	30	23	59	36
3	24	59	35	31	19	55	36
4	22	56	34	32	18	54	36
5	23	56	33	33	18	55	37
6	17	61	44	34	19	55	36
7	12	58	46	35	23	58	35
8	24	58	34	36	23	59	36
9	18	53	35	37	18	54	36
10	21	54	33	38	21	56	35
11	24	58	34	39	18	55	37
12	19	54	35	40	18	54	36
13	21	58	37	41	22	58	36
14	24	60	36	42	18	54	36
15	24	61	37	43	18	55	37
16	22	58	36	44	17	52	35
17	19	54	35	45	18	55	37
18	17	61	44	46	19	56	37
19	18	53	35	47	18	56	38
20	24	58	34	48	17	53	36
21	24	60	36	49	23	59	36
22	24	60	36	50	19	55	36
23	23	58	35	51	19	56	37
24	23	58	35	52	19	56	37
25	23	59	36	53	21	56	35
26	20	55	35	54	21	57	36
27	23	58	35	55	21	57	36
28	24	60	36	56	24	61	37
Average for all 56 locations:					**21**	**57**	**36**
Maximum for all 56 locations:					**24**	**67**	**46**
Minimum for all 56 locations:					**12**	**52**	**33**
Maximum minus Minimum:					**12**	**15**	**13**

8. Excavations of the filter bed:

There are several special studies that cannot be performed without collecting representative samples of filter media. Further, direct examination of the filter bed can reveal a great deal.

Table 5: Examination of Filter Media During an Excavation

Depth	Condition
Surface	No material on the surface Anthracite is packed down No fines, doesn't clump, sharp angular, uniform
4"	100% Anthracite, does not clump
7"	100% Anthracite, does not clump
12.5"	>5% Sand, no change in anthracite
13.5"	> 10% Sand, no change in anthracite
15"	Anthracite/Sand Interface Sand clumps, well graded, small amount of fines, does not feel dirty
16"	100% Sand, still clumps
18"	Sand no longer clumps
20"	No change
22"	No change
25"	50% gravel - Ceased excavation

Table 5 shows an example of the observations an operator made while performing a filter excavation special study during a TOP training event. The specifications for the filter bed were for 18 inches of anthracite, 9 inches of sand, 3 inches of garnet sand, and 3 inches of torpedo sand (total depth – 33 inches). Additionally, the probed depth at this location showed that there was 34 inches of media at this location. The findings reveal several useful points of information:

- The sharp, angular, and uniformly sized anthracite suggests that the anthracite is in good condition.
- The fact that the anthracite does not clump suggests that floc and other particles are not present in the anthracite. When media grains clump under had pressure, it shows that the media is capturing particles as the settled water passes through the media.
- At 12.5 inches there was 5% sand, and at 16 inches, there was 100% sand. The fact that the sand clumps shows that it was collecting floc and particles at this level.
- The presence of 50% gravel at 25 inches below the surface shows, even though the probe showed 34 inches of media at the this location, the gravel layer is disrupted and gravel is lofted during the backwash at this location and mixed with the media. The gravel should not be lofted at all.
- Finally, note the excavation was halted when the concentration of gravel was found to be 50 percent. The gravel support layer should <u>never</u> be disturbed during a filter excavation, unless the filter bed is already scheduled to be reconstructed prior to use.

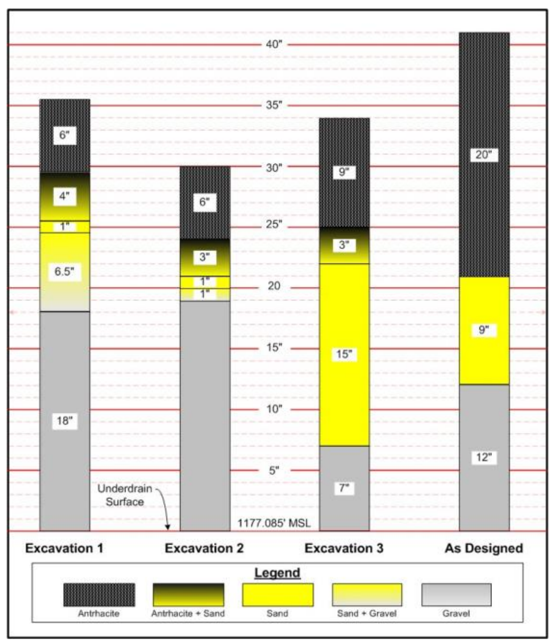


Figure 13: Filter Excavations at a Problem Plant

Figure 13 shows the findings for three filter excavations performed by the TOP for a filter that needed serious rehabilitation. The filter design is shown in the vertical bar on the right hand side of the filter. The three vertical bars on the left show what was actually found during the excavations. The figure reveals that a lot of media had been washed out of the filter or lost through the gravel support layer. The difference in the length of the bars shows that the gravel support layer was severely disrupted, providing the opportunity for greater flow at some locations more than others. For example, the flow rate at excavation 2 could be expected to be much greater than at Excavations 1 and 3, because the filter media resists flow more than the gravel.

9. Washing media samples in mild acids or bases:

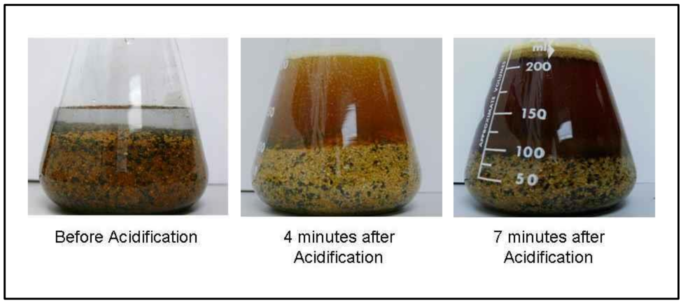


Figure 14: Removal of Mineral Deposits with Acidification

After filters have been used for a period of time it is possible for mineral or biological material to be deposited on the media. Sometimes these materials are deposited in sufficient quantities to change the shape and performance of the media. One way to evaluate whether or not this has happened is to wash the media in mild acids and/or bases. Figures 14, 15, and 16 show the results of acidification of sand media with different mineral deposits.

Figure 15: Removal of Manganese by Acidification

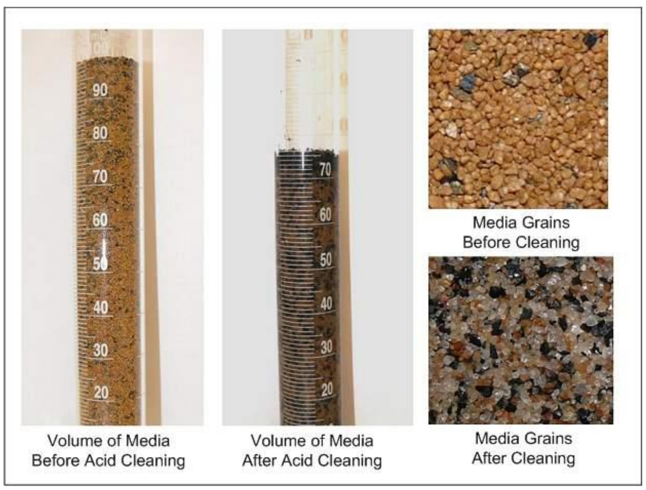


Figure 16: Volume Change as a Result of Acidification

Figure 14 shows the release of minerals into the acid used to clean the media.

Figure 15, shows the removal of manganese from sand media by acidification. One can also observe the significant reduction in volume.

Figure 16 shows the media volume change observed when the mineral deposits on the media were removed. The volume of the sand was reduced by 25 percent.

When a filter is designed, the media is specified by effective size, shape, density, and uniformity. This is because filter media with different specifications are designed to remove different sized particles. If media density relative to size is not correct, it will be washed out during a backwash. The deposition of contaminants on the media changes every one of these design factors. When media is covered by biological and/or mineral deposits, it does not perform as it was designed to.

10. Media sieve tests:

As mentioned before, the size, shape, uniformity, and density of the filter media are very important for filter performance. One of the ways to evaluate these factors for is the media sieve test. Figure 17 shows the filter sieve equipment: the sieve apparatus, the media separated by size, and the scale used to weight the separated media components.

Figure 18 shows a spreadsheet used by the TOP to evaluate the effective size and uniformity of the media layers, and Figure 19 shows how this information is used to calculate the L/d ratio. Studies have shown that media beds with a cumulative L/d ratio of 1,000 perform better than those with an L/d ratio less than 1,000. (This is also a 30 TAC Chapter 290 regulation.)

Figure 17: Filter Sieve Equipment

Effective Size and Uniformity Coefficient Calculator

Sieve No. (US Std)	Mesh Opening (in)	Mesh Opening (mm)
4	0.187	4.75
6	0.132	3.35
8	0.090	2.29
10	0.075	1.91
12	0.065	1.65
14	0.055	1.40
16	0.048	1.22
18	0.040	1.02
20	0.0386	0.980
25	0.0270	0.686
30	0.0215	0.546
35	0.0213	0.541
40	0.0150	0.381
60	0.0092	0.234
100	0.0060	0.152
120	0.0048	0.122
140	0.0041	0.104
200	0.0029	0.074
230	0.0024	0.061
270	0.0019	0.048

Sieve No.	Size (mm)	Weight of the Media (grams) Retained on the Sieve Screen				
		Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
1 (largest)	4.750	0.0001	0.00001			
2	3.353	0	0			
3	2.286	0	0			
4	1.905	0	0			
5	1.651	0	22.8			
6	1.397	0	2.3			
7	1.219	0	218.9			
8	1.016	0	0.0001			
9	0.980	183.3				
10	0.686	75.4				
12	0.546	2.8				
13	0.541	0.0001				
14						
15						
16						
17						
18						
19						
20 (smallest)						
Effective Size		**0.686**	**1.219**			
Uniformity Coefficient		**1.430**	**1.146**			

Figure 18: Size and Uniformity Calculations

$$L/d\ ratio = \sum_{x=1}^{n}\left(\frac{\text{Thickness of layer } x \text{ mm}}{\text{Effective size of layer } x \text{ mm}}\right)$$

L/d Ratio Calculator

	Media 1 (sand)	Media 2 (anthracite)	Media 3	Media 4	Media 5
Length (Depth) of the media layer (in inches)	12.0	15.0			
Effective (or Average) diameter of media in the layer (in millimeters)	0.545	0.765			
L/d ratio for the individual layers	559	498			
L/d ratio for the Filter	1057				

For Media 1 → L/d = (12.0 inches X 25.4 mm/inch) ÷ 0.545 mm = 559

For Media 2 → L/d = (15.0 inches X 25.4 mm/inch) ÷ 0.765 mm = 498

Note: Do **NOT** include any support gravel in the L/d ratio calculation

Figure 19: L/d Calculations

11.Profiles of unit performance versus plant flow:

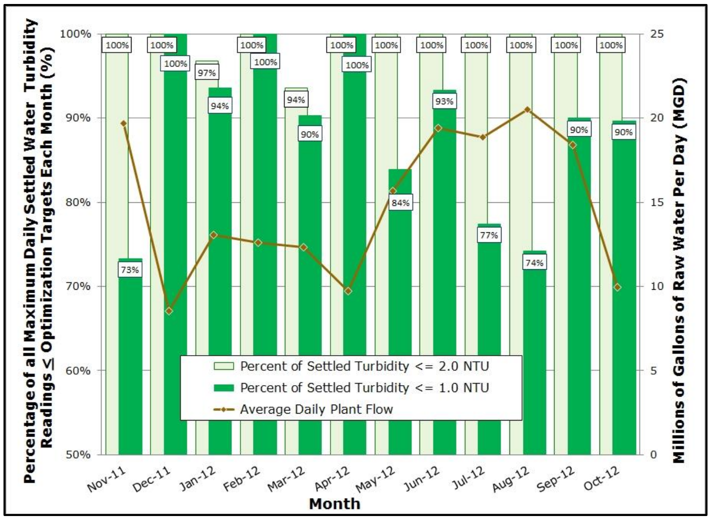


Figure 20: Basin Performance versus Plant Flow

Figure 20 presents a comparison of the sedimentation basin performance and average daily flow through the plant. Note the left vertical axis shows the percentage of time the basins met the 1.0 NTU and 2.0 NTU targets for optimized sedimentation basins. The right vertical axis shows the millions of gallons of plant flow per day for the plant where this evaluation was performed. Figure 21 shows the same graphic for filter performance during the same period.

From Figures 20 and 21, we can conclude that both the sedimentation basins and the filters failed to meet the optimization standards most often when the plant flow was 13 MGD. These data points would help the operators in their search for the reasons why the plant is yet to be optimized.

12. Other Comparisons:

There are many ways that operators may compare elements of plant performance. The following figures illustrate a few of these comparisons.

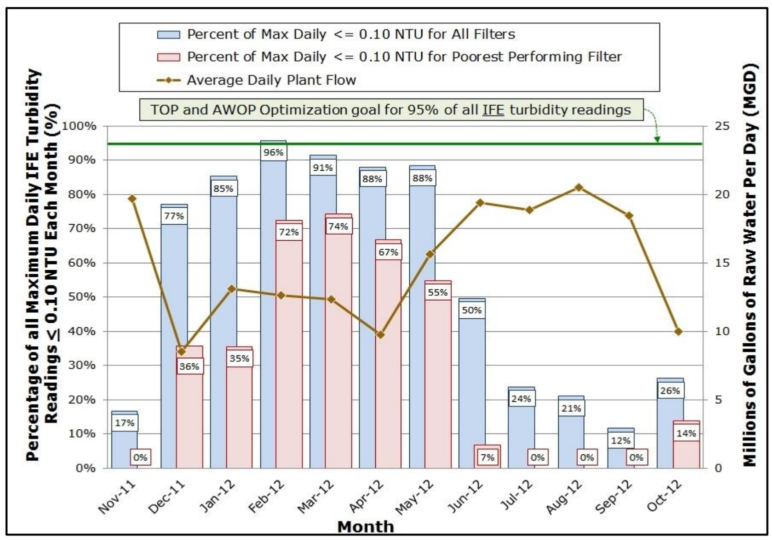


Figure 21: Filter Performance versus Plant Flow

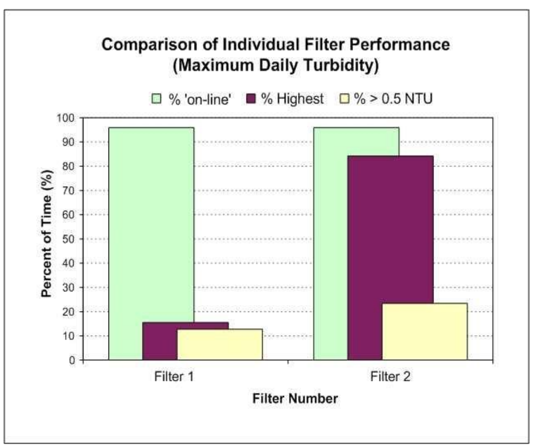


Figure 22: Comparison of Filter Performance

Figure 22 show a comparison of the performance of two filters at a plant in Texas. This chart could be useful to show the communicate the poor performance (and possible need for rehabilitation) of Filter 2.

Figure 23 shows a comparison of the performance versus the time period when the 4-hour CFE turbidity readings were recorded. The figure shows that the plant was on line 100% of the time for the 12 months in which the data were gathered, and the percentage of time the highest daily CFE turbidity was recorded during each of those 4-hour periods. Note that the cumulative percentages for the time periods exceed 100%, because sometimes the maximum daily turbidity occurred in more than one reporting period.

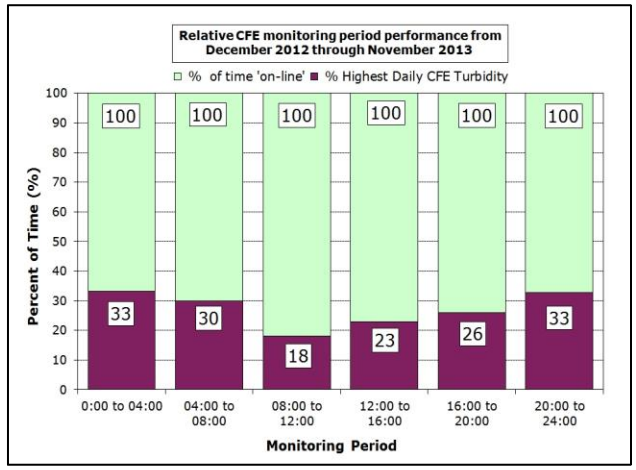


Figure 23: Comparison of Highest Daily CFE versus Time Period

Figure 23 shows that the highest daily CFE turbidity occurred most often at night. This type of chart can be used to communicate the need for additional training, or possibly additional staff, for the night shifts.

Figures 24 and 25 compare the raw water turbidity versus the settled water turbidity and the settled water turbidity versus the IFE turbidity, respectively, for a plant with serious process management issues. These figures clearly display the issues the plant was having maintaining acceptable water quality when the river that served as their water source experienced a rainfall event.

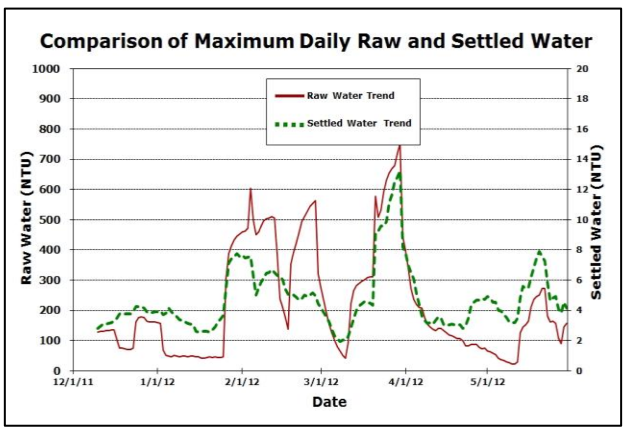


Figure 24: Comparison of Raw and Settled Water Turbidity Trends

In Figures 24, the raw water turbidity is indicated on the vertical axis on the left and the settled water turbidity is indicated on the vertical axis on the right. We can see that the raw water turbidity varied widely and the settled water turbidity mirrored this pattern though on a smaller scale.

In Figure 25, both the settled water turbidity and the IFE turbidity are indicated on the vertical axis to the left. Sometimes the filtered water trend mirrored the settled water turbidity and sometimes it did not. In any case, much of the time, the filters removed very little, if any of the settled water turbidity. At a well-run plant, it would be unlikely to see turbidity profiles of this type, but these examples show the usefulness of this tool.

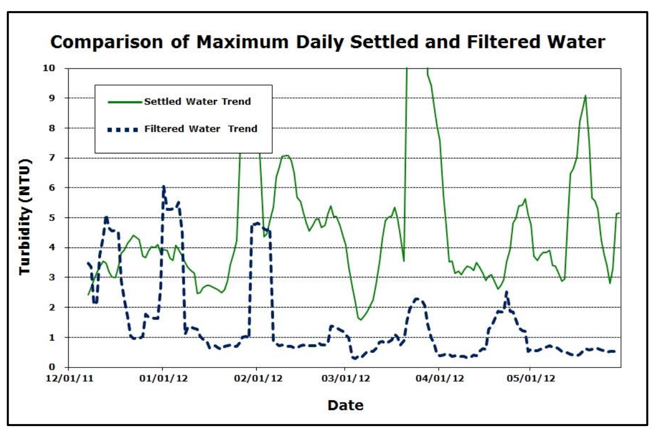


Figure 25: Comparison of Settled and IFE Turbidity Trends

Other useful comparisons include:

- Backwash water volume versus filtered water volume, which measures filter efficiency;
- Media bed expansion during backwash;
- Coagulant dose versus percentage of raw water turbidity removal by the sedimentation basins;

- Percentage of raw water turbidity removal by the sedimentation basis versus surface overflow rate;
- Percentage of settled water turbidity removal by the filters versus filter loading rate; and
- Maximum daily IFE turbidity versus maximum daily CFE turbidity, etc.

The performance status special study is a powerful tool the operators can use for determining maintenance needs and evaluating the treatment strategy.

The "Why is the water quality changing?" Special Study

The first type of special study we will look at is the simpler of the two: the "**Why?**" process.

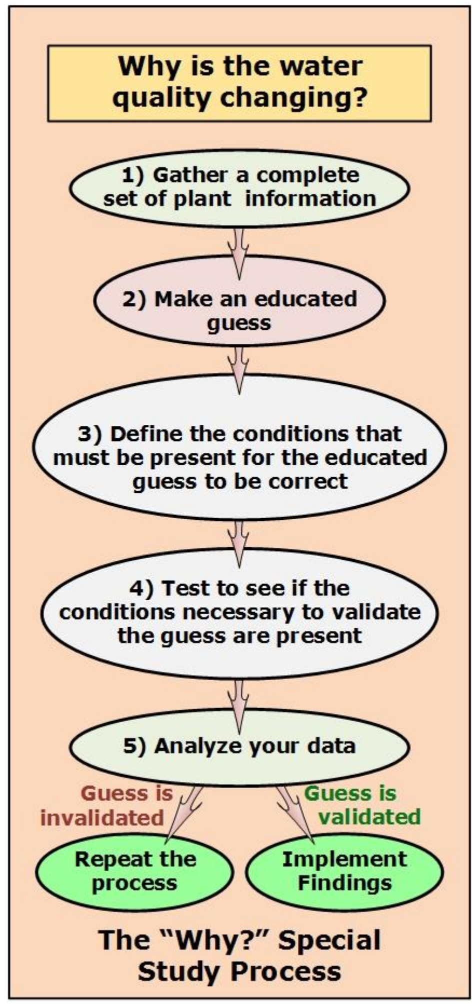


Figure 26: The "Why?" Special Study

Figure 26, to the right, shows the steps for implementing a "Why?" Special Study. This special study normally involves laboratory analyses or operations protocols that are beyond those used for routine monitoring and operation.

Very generally, the "Why?" special study proceeds in the following way:

- The first step is to gather a complete set of plant information. Without the complete set of plant information, we are not going to be as efficient as we could be.
- The second step is to develop the educated guess (or theory, or hypothesis), to provide a sense of direction for subsequent evaluation.
- The next step is to define the conditions that must be present for an educated guess to be correct.
- Then we perform tests to see if the conditions necessary to validate the guess are present.
- We then analyze our data, and
- Repeat, if necessary, or implement our findings.

Gathering a complete set of plant information

After we have decided on the type of special study we are going to pursue, we assemble our plant information. Making photocopies or printouts of plant information is useful, in that we have to have something we can take notes on if we are prone to work that way. This helps prepare formal documentation for the study for our plant files. Also, we probably don't want to make handwritten notes on official plant records, so having an extra copy to work on will be a good thing. The most important data assembly is what happens inside your own head, but writing it down allows you to transfer the information to another operator and/or allows you to revisit the issue at a later time.

You may want to gather additional information from other sources, but many times, it may be necessary to proceed with only the information that is immediately available.

Making an educated guess (developing theory or hypothesis)

To investigate any matter, there has to be a frame of reference within which to evaluate the issue and experimental information you assemble. Your educated guess (also known as a hypothesis) provides the framework with which you will organize all your preliminary information and the data you produce by experimentation. Without an educated guess, you have no way to proceed.

Figure 27 shows a simplified diagram explaining how your educated guess(es) might come about. If you only have one possible cause, write it down. If there are more than one, you will want to list them and prioritize the sequence you evaluate the guesses for why the water quality is changing.

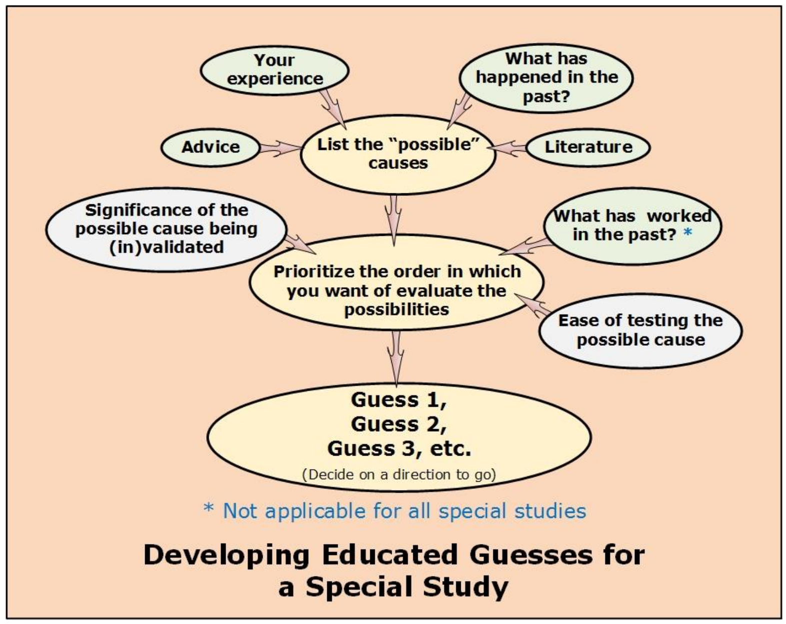


Figure 27: Educated Guesses (Hypotheses)

The priority for each guess is typically based on:

- Your experience,
- What has happened in the past,
- Advice you get from people you trust, and
- Literature (periodicals, reference texts, guidance from the EPA web-site and other on-line sources, etc.).

There may be other sources of information that you have and if you value them, use them. Also, don't be intimidated by the fact that a guess may be wrong. If the guess is wrong, you will probably prove it is wrong, and then you will have data to prove it to others, as well. It is important to eliminate incorrect solutions methodically, or people may adhere to inaccurate assumptions.

Define the conditions that must be present for the educated guess to be correct

1. For every condition you are trying to evaluate, there must be a process for deciding whether a particular guess is correct or incorrect. For example, if I guess a change in water quality is due to a shift in pH, I have to:
   - Prove that the pH is changing, and

- Prove the change in pH is large enough to be a factor in the water quality changes we are evaluating, and
- Document that a pH change can cause the water quality issue being evaluated using a technical reference.

2. This will require some practice, but your instincts will serve you well.

Perform tests based on the educated guess and the parameters you have selected

You want to see if the conditions exist that will prove or disprove your guess (validate or invalidate the hypothesis), and these are different from event to event. Some general guidelines include:

- Perform all the tests using the precise procedures in the guidance documents for your test instruments (if applicable).
- Perform all tests using precisely the same laboratory technique for each series of samples.
- If you are artificially changing the water quality in your test runs, **only change one water quality parameter at a time**.
- Document the tests and test results to only the number of significant digits that your test procedure indicates is justified.

Analyze your data

Water operators analyze data constantly. They review data produced by on-line instruments and SCADA displays and decide whether or not the current results, the short-term trends, and the long-term trends are what they want. Analyzing special study test results is often just as simple.

1. Analyzing data could include complicated statistical analyses, but this is seldom required at the water plant.
2. If you have several data points, an easy way to analyze the data is to plot it on a chart. If you only have a couple data points, the chart is probably not necessary.
3. The product you produce from your data analyses is a conclusion that your educated guess is validated or invalidated.
4. If the data support neither conclusion, you need to refine the guess and the parameters you are testing.

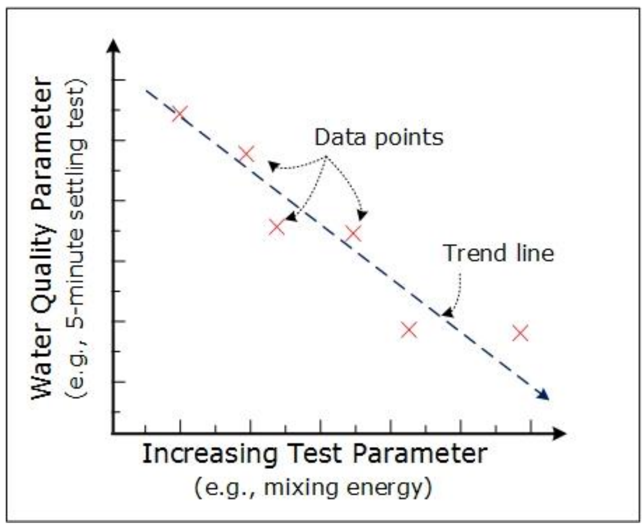


Figure 28: Trend chart

Example of the "Why is the water quality changing?" process

As an example, let's look at a situation the TOP evaluated at a plant that was having trouble meeting the CFE turbidity limits. We considered that the problem was unusual because the IFE turbidity for both plant filters was lower than 0.1 NTU, but the CFE turbidity was nearly 0.3 NTU all the time.

We wanted to know, "Why is the water quality changing between the IFE turbidity monitoring point and the CFE turbidity monitoring point."

1. As part of the evaluation, we collected and examined the plant information, including a schematic diagram of the plant. The diagram is shown, below.

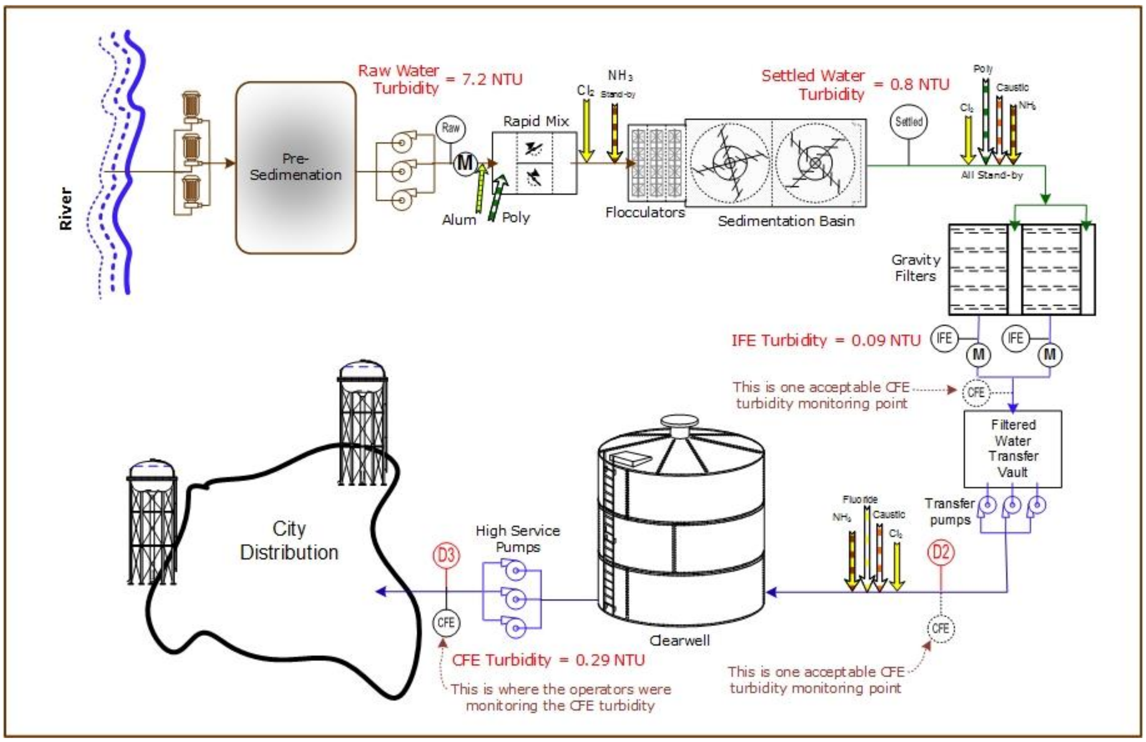


Figure 29: Example – Information Gathered for a "Why?" Special Study

2. We examined all the chemical feed points and we looked at all the monitoring points as well.
    - One of the first things we observed was that the CFE monitoring point was not immediately downstream of the filters -- it was downstream of the clearwell.
    - We also observed that the operators were adding caustic downstream of the filtered water vault. This would definitely change the quality of the water, but would it change the turbidity?
    - During a plant tour, we observed that the operators appeared to be adding more alum than might be required for the water they were treating, especially since they were using a coagulant aid.

3. We then listed the possible causes of the increased turbidity leaving the clearwell:
   - It was possible that the on-line CFE turbidimeter was not calibrated correctly and it was reading higher than it should.
   - It was possible that both of the on-line IFE turbidimeters were not calibrated correctly and they were reading lower than they should.
   - It was possible that the change in pH caused something that was soluble at a lower pH to precipitate from the water at the higher pH in the clearwell. Common constituents that would do this include:
     - Iron
     - Manganese
     - Alum
   - The clearwell contained sediment.
4. We had four educated guesses to evaluate.

   Educated Guess 1 - The on-line CFE turbidimeter was not calibrated correctly.
   - To evaluate this guess we checked the calibration date on the turbidimeter and the electronic record said that it had been calibrated with a primary standard three days before our arrival. (On-line turbidimeters only have to be calibrated with a primary standard every 90 days.)
   - We also did a comparison check between the on-line CFE turbidimeter and with a newly calibrated benchtop turbidimeter and they read within .02 NTU of each other.

   Therefore, Educated Guess 1 was invalidated. We wrote this down and it became a part of the official record of this event.

   Educated Guess 2 - The on-line IFE turbidimeters were not calibrated correctly.
   - To evaluate this guess we checked the calibration date on the turbidimeter and the electronic record said that they had been calibrated with a primary standard three days before our arrival.
   - We also did a comparison check between the on-line IFE turbidimeters and with a newly calibrated benchtop turbidimeter and the online turbidimeters were within 0.01 NTU of benchtop reading.

   Therefore, Educated Guess 2 was invalidated. We wrote this down and it became a part of the official record of this event.

   Educated Guess 3 - The change in pH caused something that was soluble at a low pH to precipitate from the water at a higher pH.
   - With this guess, we had three possible constituents we could evaluate (iron, manganese, and alum), so we first discussed this with the operators.
   - The operators reported that they had never had a manganese problem but they had seasonal problems with iron and that they checked for it weekly. We asked them to

perform an iron test on the raw water, and the iron level was 0.02 mg/L. The iron level was so low that the operators would not have considered it a problem.

- We then decided to evaluate the possibility that some of the alum was reaching the clearwell and precipitating as the pH changed.
  - We conducted pH and turbidity tests at different points in the plant to determine if the change in pH tracked with any changes in aluminum content and turbidity. We found that they did.
  - We then tested for aluminum (aluminum is readily detectable when present as aluminum sulfate or aluminum hydroxide) in the water leaving the filters and leaving the clearwell. The results, presented in Table 2, show:
- The pH at the settled water and IFE sample points was below 5.5, which is the lowest target pH when using enhanced coagulation for TOC removal.
  - Enhanced coagulation was not a goal at this plant.
  - References recommend maintaining a pH higher than 5.5 to avoid dissolving alum in the sedimentation basins.
  - Dissolved alum does not form floc and will not settle.

Table 6: "Why?" Special Study Data

Location	Temp (ºC)	pH	Turbidity (NTU)	Iron (mg/L)	Aluminum (mg/L)
Raw H2O	23.0	6.1	7.2	0.03	n/m*
Settled H2O	22.5	5.3	0.8	n/m*	n/m*
Filtered H2O	22.2	5.1	0.09	n/m*	0.6
CFE Tap H2O	20.5	5.5	n/m*	n/m*	n/m*
Finished H2O (D3)	22.7	8.6	0.29	n/m*	0.2

* n/m = not measured

- There was more aluminum in the water leaving the filters than is allowed by the TCEQ and EPA treatment standards. (The high-range secondary standard for aluminum is 0.2 mg/L and the level coming out of the filters was three times that.)
- There was a reduced amount of aluminum in the water at the entry point. However, the only place for the aluminum to drop out of solution was to precipitate in the clearwell. The alum (aluminum) was coming out as "after floc" and that was causing the high CFE readings with the sample tap after the clearwell.
- We also noted from the EPA's *Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual*, EPA 815-R-99-012, May 1999 said this about the solubility of aluminum at low pH:

  "The minimum solubility of aluminum occurs at a pH of 6.2 to 6.5. Utilities operating at a pH of less than 6.0 that do not increase the pH before filtration may be impacted the most due to the solubility of aluminum at this pH.

Aluminum solubility also increases significantly above a pH of 8.0. If a utility practices enhanced softening and does not adjust pH before filtration, aluminum carryover problems may result."

- While aluminum solubility would increase as pH rises above 8.0, the degree of solubility at 5.1 and 8.6 would not be expected to be precisely the same.

  Therefore, Educated Guess 3 was validated. We did not evaluate Educated Guess 4. We wrote this down and it became a part of the official record of this event.

The "How can we improve water quality?" Special Study

The "How?" special study requires a few more steps and a revision of the sequence of steps.

When we are trying to find a solution to a treatment problem without fully understanding why the problem came about, we are essentially taking a stab in the dark. <u>This is not a bad thing</u>, because that is the way scientists have been conducting research for centuries. In fact, the "Scientific Method" was developed to deal with just that situation: there are some things we don't understand about the treatment process, but we want to experimentally figure out what water quality parameters exist that allow us to make treatment changes that will result in better water quality.

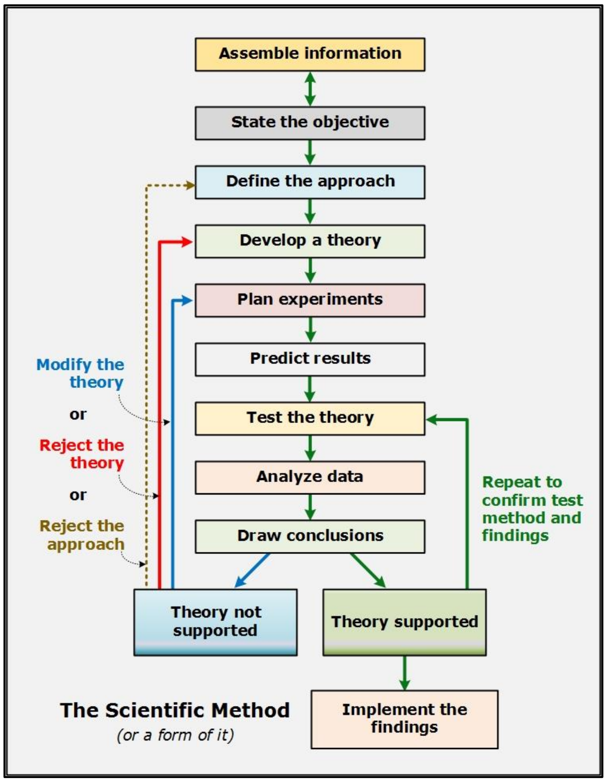


Figure 30: Modified Scientific Method Implementation

1. The EPA Technical Support Center (TSC) has been working on applying the scientific method to SWTP processes for several years. We use a modified version of the TSC process, and incorporate the Special Study process we have already discussed. Figure 30 shows our modified scientific method.[2]
2. In this version of the scientific method we reordered, split, and further defined some of the steps. These revisions are specifically for adapting the process for use by persons who don't have an academic background in research science disciplines.

[2] There are many versions of the scientific method. Each is designed for a general or specific application, so our presentation here is not parallel to every version of the method with which you are familiar.

3. We have already discussed the first elements of the Special Study process in talking about the "Why?" special study, and in many respects, these are similar to those for the "How can we improve?" special study.
4. Once we have recognized that there is a problem and/or goal, and have decided to do something about it, we proceed by implementing our scientific method. Very generally, our scientific method process is implemented by these steps:
   - Gather information.
   - State the objective.
   - Define the approach.
   - Develop a theory (hypothesis or guess).
   - Plan experiments.
   - Predict results.
   - Test the theory.
   - Analyze data.
   - Draw conclusions, and
     - Retest to confirm the test method and the test results, or
     - Modify the theory and repeat the test process, or
     - Reject the theory and develop a new theory, or
     - In some instances, we might reject the approach and develop a new one.
   - Implement your findings.

Gathering information:

1. As stated earlier, the most important data assembly is what happens inside your own head. Your experience with your plant will often lead you to an idea for how to evaluate what is going on in your plant without additional information or documentation. Just remember:
   - What is inside your head cannot be read by other operators and/or administrators, and may not even be retrievable by yourself in a few weeks or months' time.
   - It pays to document the information you gather as often as it is practical. If an urgent need prevents you from documenting your information gathering in advance, then document it after the fact. But don't wait too long.
   - The information you gather is a part of the event. If something similar happens in the future, it is prudent to look at your record of the event in light of all of the information you had at the time. Without this information, you may misapply your special study results.
2. Probably the first data set you want to collect is the performance status of your pumps, motors, mixers, feeders, monitoring equipment, etc. We want to know that we are dealing with a treatment strategy issue and not a maintenance issue.
3. Information comes from a lot of sources. We can use information from:

- Routine monitoring and recording;
- Special analyses that are beyond what we normally do;
- Professional journals/periodicals or technical references; and
- Guidance from other operators, engineers, or technical experts we trust.

4. It is important, though, that we don't get so bogged down in collecting information that we do nothing about it. If we later find out that we didn't have enough information to analyze and resolve our problem, we can go back and get some more. When we get to the next step, stating the objective, we may find that we want to go back and collect more information, because there is an element of the objective about which we do not have sufficient knowledge or technical information. When this happens, it is not a failure in our gathering of information, it is only a part of the process and an element of being thorough.

Stating the objective:

Our objective will always be to produce drinking water that is safe for consumption, but special studies do not always have to do with solving treatment problems. Sometimes we just want to produce safe water more cheaply or to produce water that meets the optimization recognition goals. Stating the objective is an important step. When we meet the objective we know that our special study produced acceptable results; when we don't meet the objective, we know we need to perform more special studies. In other words, our objective defines the end point in applying our special study process.

Table 7: Comparing General and Specific Objectives

General Objectives	Specific Objectives
Maintain the desired IFE and CFE turbidity levels	Maintain the desired IFE and CFE turbidity levels **below 0.1 NTU**
Maintain the entry point disinfectant residual high enough to maintain a residual throughout the distribution system	Maintain the entry point disinfectant residual **above 2.0 mg/L**
Maintain acceptable disinfectant residuals in the distribution system	Maintain a disinfectant residual in the distribution system **above 1.5 mg/L**
Reduce treatment costs	Select a coagulant aid that will result **in lower coagulant doses and produce less sludge**
Minimize the peak turbidity and duration of the post-backwash turbidity spike for filters	Modify the post-backwash turbidity procedure to maintain a peak IFE turbidity of **less than 0.3 NTU** and return the IFE turbidity to **less than 0.1 NTU in 15 minutes or less following backwash**
Minimize disinfection byproduct formation in the plant	Keep TTHM formation in the plant **below 0.040 mg/L**
Minimize disinfection byproduct levels at the monitoring points	Maintain the TTHM at the monitoring points **below 60 ppb**

1. There is more than one way to define the objective. We can decide on a general objective or a specific one. Which one we decide on is normally based on whether or

not we have an immediate need to resolve a problem or we want to achieve a long-term treatment goal. Table 7 displays the difference:

2. In many instances, the objective will be obvious. If we are producing water that has an unacceptable turbidity, our objective will be to modify the treatment strategy to meet our turbidity goals. Sometimes the objective may be more complicated and can sometimes be multi-faceted.
3. If you have an urgent objective, your theories may end up being more radical, that is--designed to achieve a larger incremental improvement in water quality with implementation of a single treatment change. However, if you have a long-term treatment goal, your theories may be more refined and you may choose to link several theories that can be proven one at a time so that, when pieced together, they will result in an improved and more cost-effective treatment strategy.
4. If you work with a group, consider brainstorming to ensure the objective is stated clearly and represents a consensus approach.
5. Bottom line: Don't disregard stating <u>and</u> <u>recording</u> your objective.

Defining the approach:

1. We have stated our objective, which helps us know when we reach the end-point of our special study, now we must decide how we are going to reach, or at least make progress, toward that goal.
2. Describing the approach and writing it down helps us to focus more directly on how to proceed. It also helps us divide our information into what is useful and what is less useful. Moving from the objective requires us to make an educated guess, just like we did in the "**How?**" special study. However, in this instance, the "guess" has to be reworded or made more specific to define an approach.
3. Figure 31 shows how the TOP team developed an approach to help a treatment plant where the plant was producing water with turbidity five times higher than the raw water turbidity. There were a lot of observations, but there is really only one real objective: restore the function of the plant to where the IFE and CFE turbidity levels met the plant goals. (In this instance the operators only wanted to meet minimum regulatory requirements.) The objective didn't require much thought: it was completely obvious that we wanted to restore the plant to regulatory compliance.

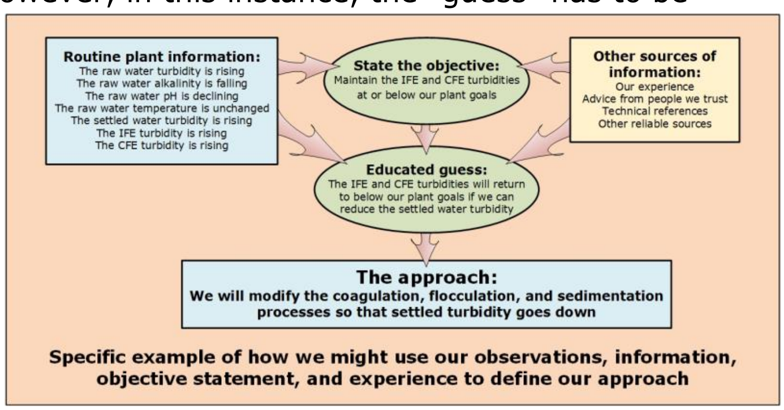


Figure 31: Example for Defining the Approach

4. Defining an approach will help us put our observations, knowledge, and other information we gathered into perspective (see Figure 31). At this point, we need to consider:
    - Is the information we have relevant to the approach?

- Do we have "all" the information we need to evaluate the approach?
- Is there an area that we need to study to have a complete set of information (or as full an understanding as we need) to continue our special study?
- Having gathered additional information, does our approach hold up? Do we need to modify our approach?

5. Defining the approach allows us to develop theories within a more limited area of investigation. While it is useful to keep an open mind about possible solutions to a problem, the scientific method is devised to test a single theory at a time. Defining the approach allows us to develop theories that fit into our understanding of that area of investigation. If we exhaust our theories without reaching the improvement in water quality that we need, we can then go back and try a different approach.

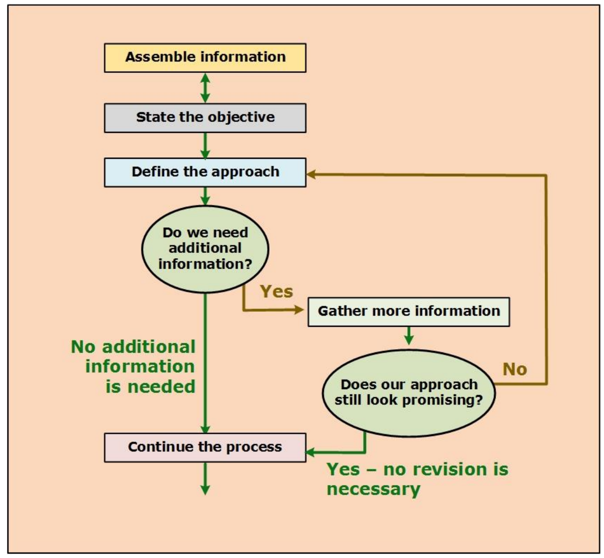


Figure 32: Firming up the Approach

Developing a theory based on your approach

We develop theories based on our approach. From Table 6, we see that objectives for different situations will be significantly different. Consequently, our approaches to meeting different objectives vary by a very wide range. For this reason, we cannot present an exhaustive list of approaches or theories that might be developed for all the different situations where the special study process might apply.

1. A theory is an idea that adjusting a particular parameter of the treatment process will bring a positive change that will help us meet the objective.
2. For the sake of illustration, we will use the problem and approach developed in Figure 6, on the previous page, to begin developing one or more theories to evaluate, one at a time. We will list and prioritize as many theories as we think desirable. Even if the first theory turns out to be correct and produce positive results, the theories we placed a lower priority on may also help us improve our treatment.
3. The approach, "Modify the coagulation, flocculation, and sedimentation processes so that the settled water turbidity goes down," provides the context for our theories.
4. When we have had a longstanding experience with a particular source water, there are probably some likely theories that will immediately come to mind, but sometimes we will want to expand our alternative theories to try something we haven't done before.

5. We might try considering as many of the factors that influence the coagulation, flocculation and sedimentation processes of which we are aware. Many of these are shown in Table 8.[3]

Table 8: Factors Influencing the Processes in the Approach in Figure 31

Factors influencing coagulation	**Factors influencing flocculation**	**Factors influencing sedimentation**
The level of turbidity present The types of turbidity present in the raw water (clays, silt, algae, organic and inorganic compounds, plankton, other organic material, etc.) The presence of salts and sulfates Types of coagulant and coagulant dose Type of coagulant aid coagulant aid dose Mixing energy Mixing time Temperature, pH, and alkalinity of the water	The effectiveness of the coagulation process The presence or absence of a flocculation aid Flocculation energy for each phase of tapered flocculation Time for each phase of tapered flocculation Low energy transition from the flocculation zone into the sedimentation zone.	The effectiveness of the coagulation and flocculation processes The surface overflow rate of the sedimentation basin The detention time in the sedimentation basin The effective management of settled solids in the sedimentation basin The low energy transition from the sedimentation basin(s) to the filter(s)
Factors influencing all three processes		
The presence of short-circuiting of flow through the treatment units Improper design and/or construction Malfunctioning equipment		

6. It is possible that we could develop a theory about each one of the elements influencing coagulation, flocculation, or sedimentation, but we don’t really need to.
   - As an example, developing a theory that takes into account the type of turbidity in the raw water (are the particles in the raw water positively charged, negatively charged, etc.) requires lab work using equipment that most drinking water treatment plants do not have.
   - Another factor is that there are some parameters influencing the coagulation, flocculation, and sedimentation processes that are not easy to adjust. For example, the detention time in the rapid mix, flocculation chambers, and sedimentation basins are normally based on the raw water flow rate which is determined by treated water demand.
   - We want to move ahead, not get bogged down with things we can do nothing about.

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[3] This is not intended to be exhaustive lists of the factors influencing coagulation, flocculation, and sedimentation.

7. Some of the issues in Table 7 are preventive and/or corrective maintenance issues and not a special study issues. These issues would become part of a special study if maintenance must be delayed: in other words -- we have to make the treatment process as effective as possible until the maintenance can be performed.
8. For the situation in our Figure 31 example, we have gathered plant process information and it can help direct us in developing theories. We know:
   - The raw water turbidity is rising (nothing we can do about that),
   - The raw water alkalinity is falling, and
   - The raw water pH is declining.
9. We also know:
   - The coagulant (alum, in this instance) and/or coagulant dose is not as effective as it used to be, and
   - The coagulant aid and/or the coagulant aid dose is not as effective as it used to be.
10. From personal experience or from our reference materials, we also know:
    - The optimum pH for coagulation with alum is 6.8 to 7.5, but water plants commonly use alum in the pH range from 5.5 to 8.0.
    - A bicarbonate alkalinity of 0.5 mg/L is required for each gram of alum used for coagulation.
11. In the Figure 31 example, we have a common theme: some of the raw water qualities that influence coagulation are changing, and these are water quality parameters that we have the knowledge and equipment with which to conduct experiments.
12. We also want to improve the flocculation and sedimentation processes, but we know that the coagulation process influences the flocculation process, which then influences the sedimentation process. By developing theories for investigation of the coagulation process, we are moving our evaluations to the earliest phase of the treatment process in our approach. If one of the theories involving coagulation can be validated, we would expect the flocculation and sedimentation processes to improve by implementing our proven theory. Should these theories be invalidated, we can move down the treatment process for more alternative theories for adjusting the treatment strategy.
13. Obvious theories concerning coagulation might include:[4]
    - The higher turbidity requires a different (but not necessarily higher) coagulant dose.

[4] This is not intended to be an exhaustive list.

- The raw water now requires the use of a different coagulant.
- The raw water requires a different coagulant aid dose.
- The raw water now requires a different coagulant aid.
- The raw water needs additional alkalinity for effective coagulation with alum.
- The pH of the water must be adjusted prior to addition of the coagulant.
- The flash mixing energy is inadequate to provide effective coagulation.
- The flash mixing energy is too high and coagulated particles are torn apart prior to leaving the flash mixer.

14. We could have provided more definition with our theories. For example, instead of saying, "The raw water properties require a different coagulant aid," we could have said, "The raw water properties now require that we change from a cationic polymer to an anionic polymer as a coagulant aid." Providing this much specificity might be good in many situations, especially if it will lead us to evaluating possibilities that we would not normally ignore. We have already limited our pool of theories by selecting an approach: we don't want to further limit the theories we evaluate due to our individual preferences or the biases of the distributor who sells us chemicals.

Planning experiments:

We have already stated that our theories should be theories that we can test. If none of our testable theories work, we can then move on to those that we would need outside help to evaluate.

1. If we were planning experiments for the situation described in Figure 31, our planning process would be straight forward and defined by the representative jar test procedure we use at the plant. In other words, we assemble the jar test equipment, read the jar test SOP, obtain samples of the coagulants and/or coagulant aids we want to try, and collect enough raw water to run multiple series of jar tests.
    - However, our planning would add components to our test process that define:
        - The order in which we are going to evaluate the coagulants and/or coagulant aids,
        - The dose change we will use from jar to jar for each test series,
        - The duration of each mixing speed we use and the settling time we use based on the detention time and/or surface overflow rate in each zone.
    - Another important issue for planning is that, if we have a 45-day supply of coagulant at the plant and there is no facility for storing an adequate supply of an alternate coagulant, our planning will probably not include evaluating alternate coagulants until the other theories are exhausted.
2. Planning test procedures to conduct evaluations for which we don't have a written SOP require more time and effort to develop the test procedure and to identify the resources necessary to conduct the tests. For example, if we are evaluating the

backwash procedure for a filter that does not remove as much turbidity as other filters receiving the same settled water at the same loading rate, we may be defining a whole new test process. Even so, the test procedures still have to use equipment and resources we have on hand or can easily obtain.

3. In developing a test procedure, the test parameters should include:
    - Evaluation of the current situation – the baseline (if necessary),
    - Adjustment of the parameters in a controlled way so that the test results can be accurately quantified and documented, and
    - Adjustment of only one parameter at a time so that the influence of each element of the process is accurately determined.
4. The importance of evaluating one parameter at a time cannot be overstated. Our best treatment adjustments may come from changing multiple parameters, but when we change multiple parameters in performing a test, we do not know if one of the changes was actually irrelevant. Failure to evaluate one parameter at a time can result in costly mistakes.
5. We must also decide on how many times we are going to run each test to evaluate our theories (if applicable). If the situation is urgent, we may be inclined to perform one test to prove or disprove a theory, but repeated tests with the same or similar results is the preferred way to validate of invalidate a theory.
6. For theories about treatment modifications that must be conducted on a plant scale, rather than in the plant laboratory, we will need to decide how long we are going to continue the test to determine whether or not our theory is validated. An example of this might be attempting to control algae by using a coagulant with copper sulfate in it versus adding copper sulfate at the raw water pump station. We can try these two alternatives, but we need to decide how long we are going to run each phase of the test.

Predicting results:

We predict our test results to decide what degree of improvement of the treatment process constitutes validation a theory. Part of the test planning includes evaluating the current plant conditions. Predicting results is simply saying: if the water quality improves by a certain amount above the baseline quality when we test our theory, we have proven the theory valid. We must do this because:

1. Experiments are subject to error and random deviation. A modest improvement or degradation of water quality during a particular test may be due to either one of these factors. We do not want to start making wholesale changes to our treatment process based on a test result that does not conclusively validate our theory.
2. There is a mathematical science of statistical analyses that are used to show the correlation between one parameter of a treatment process and another. These analyses produce "confidence limits" which tell us how likely a treatment adjustment produced a positive or negative change in water quality. We are almost never using

these analyses for making urgently required treatment changes, and are probably not using them long-term special studies for refining our treatment strategy. Consequently, we have to substitute a way to measure our test results.

3. Predicting results is not a matter of being right or wrong: we are trying to determine whether a particular test result is significant or indeterminant.
    - A significant test result is sufficient to validate or invalidate a theory. Therefore, the "significant" measure must be defined for both contingencies.
    - An indeterminant test result means that the theory is neither validated nor invalidated. This means either that additional testing may be required or that the theory cannot be proven or disproven with the test you are using.
4. Predicting results that matter is not as hard as it may sound. We have regulatory treatment technique requirements we must meet. Further, we have individual treatment unit goals. With practice, we learn the degree of improvement that must be shown in a test to demonstrate whether or not the theory being tested will actually produce positive results that will allow us to meet these requirements and goals.
5. Some test results (for example, controlling algae with the addition of copper sulfate at different locations) may not be easily measured without some imagination. If we routinely evaluate the types and quantities of algae in our raw water, we may have a reference point to evaluate a reduction in algae growth in our basins and filters. However, if we do not routinely perform these analyses, we may have to invent a new way to quantify the baseline algae growth and the degree to which algae growth is being reduced to validate or invalidate our theories.

Testing the theory:

Testing our theories requires that we perform our tests using consistently valid test methods and procedures. Specifically:

1. When we are using analytical techniques we perform routinely, follow the existing quality assurance and quality control (QA/QC) procedures to ensure we are performing those tests accurately and consistently for special studies we should conform to these same standards.[5]
2. If we are performing a test we do not routinely perform, we need to follow the QA/QC procedures recommended by the manufacturer of the test equipment.
3. If the test we are performing does not include the use of instrumentation used in the normal way, there are things of which we must be aware:
    - Our test procedures must be consistent from one test run to the next.

[5] This is not a regulatory requirement for process management tests, but it is often a good protocol.

- If we adjust a test parameter to determine its influence on the treatment process, all other test parameters should be kept the same until we have completed testing that parameter.
- If one theory is validated, we may want to test other theories, as well. If several are validated, we may be able to apply more than one theory to improve the quality of our water far above the level we would have achieved if we implemented only one theory.
- If we have validated one theory, when we test other theories, we should optimize implementation of that parameter before testing the next theory. This should allow us to maximize the adjustment of our treatment strategy.

Analyzing the data:

Analyzing the data involves comparing our test results to the expected results, generally in graphs and tables. The trends can reveal whether or not our predictions were accurate and whether or not the test results are significant. Data analyses are facilitated by constructing tables and/or charts similar to the one in Figure 28.

The graphs and tables should be clear, so they can be used to report the results and explain what they show.

Drawing conclusions:

Earlier, we discussed the predicted results for our tests. The analyses of our test results show whether or not our expectations were realized. We have to revisit those expectations based on our experience with the testing procedure and data analyses. We basically need to decide:

- Our theory was validated,
- Our theory was invalidated, or
- We need to do more testing to know whether or not the theory was validated or invalidated.

Our decision should be based solely on the test results and analyses, and not on personal preference. When the theory is validated, we should confirm this with additional testing if time permits. If time does not permit, do the additional testing anyway. When the theory is invalidated, we need to evaluate another theory, and in rare instances, come up with another approach.

Implementing the findings:

When our theories are validated, the next logical step is to modify our treatment strategy based on our conclusions. If this is impractical, we were probably using the wrong approach or theory. The point of the special study is to determine what we can and should do at the treatment plant.

Attachment 1 to the Course Manual

Performance Status Special Study Form

Directed Assistance Module 9

Special Studies at the Water Treatment Plant

Special Study Format and Elements[6]

(Use all elements that are relevant to your study)[7]

Special Study Topic: Identify the name of the special study and briefly describe why the study is being conducted (i.e., one to two sentences).
Gather a Complete Set of Plant Information: **Make an Educated Guess (develop a hypothesis):** Describe what is to be proved by completing the study (show cause/effect relationship). Focus study on a specific activity. **Define the Conditions That Must be Present for the Educated Guess to be Correct:** Describe how the study will be conducted (i.e., processes and equipment involved). Describe resources required (i.e., staff, sampling, and testing). Involve plant staff in development (operations, maintenance, and laboratory). Determine whether any background data is needed before initiating the study. **Test to See if the Conditions Necessary to Validate the Guess are Present:** Define the time estimated to complete the study (important to clarify for staff). **Analyze Data:** Describe expected results from the study. Describe how the data will be presented to support the hypothesis. Define measures of success for the study. **Summary & Conclusions:** To be completed at the end of the study. Document results of the study (brief written summary with charts). Present findings to utility staff and management (use as training tool for all utility staff). **Implementation:** To be completed at the end of the study.

[6] This form was originally developed by the EPA Technical Support Center and Process Applications of Colorado Springs, Colorado.

[7] Not all of the steps in this procedure are used for all Performance-Status special studies.

Document changes to current plant procedures, based on study results.

Special Study Format and Elements

Special Study Topic:
Hypothesis:
Approach & Resources:
Duration of Study:
Expected Results:

Summary and Conclusions:
Implementation:

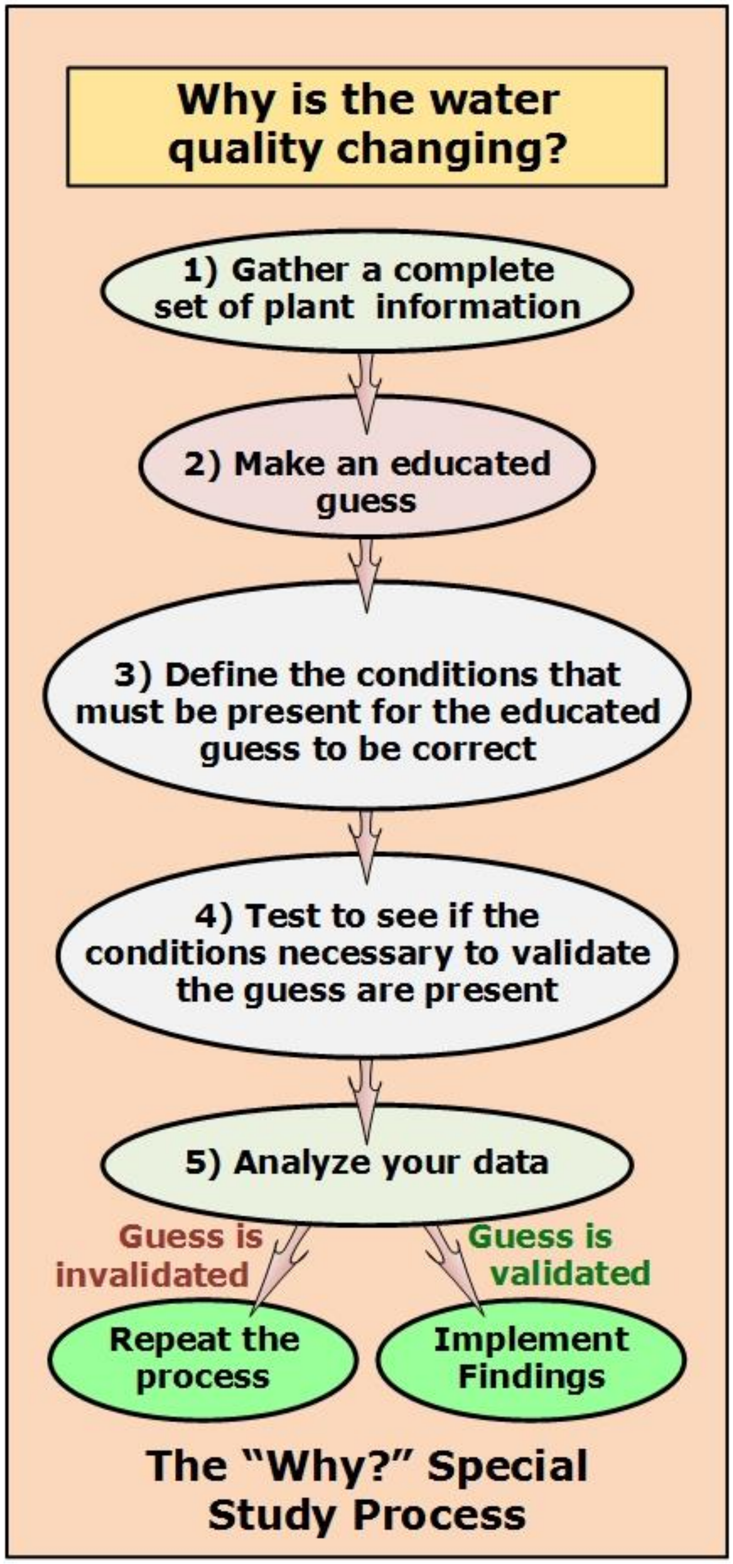
Attachment 2 to the Course Manual

"Why is the Water Quality Changing?" Special Study Form

Directed Assistance Module 9

Special Studies at the Water Treatment Plant

The "Why?" Special Study



Special Study Format and Elements

(Use all elements that are relevant to your study)

Special Study Topic: Identify the name of the special study and briefly describe why the study is being conducted (one to two sentences).

Gather a Complete Set of Plant Information:

Assemble a complete set of information on the plant status to ensure issues related to reliability of instruments and equipment is not an issue. (Use the form provided)

Assemble information related to the issue at hand. Focus study on a specific activity.

Make an Educated Guess (develop a theory):

List the possible causes for the change you are observing (show cause/effect relationship).

Prioritize the possible causes for evaluation.

Define the Conditions That Must be Present for the Educated Guess to be Correct:

For every possible cause, there are a set of conditions that must be true for the cause to be present. These must be enumerated.

Test to See if the Conditions Necessary to Validate the Guess are Present:

Perform all the tests using the precise procedures in the guidance documents for your test instruments (if applicable).

Perform all tests using precisely the same laboratory technique for each series of samples.

If you are artificially changing the water quality in your test runs, only change one water quality parameter at a time.

Analyze Data:

Assemble your test results in a way that shows the direct relationship between the parameter you are testing and the test results.

Describe how the data will support your educated guess(es).

Implement Findings:

To be completed at the end of the study.

Document any changes to current plant procedures (if applicable), based on study results.

Special Study Topic:
Gather a Complete Set of Plant Information:
Make an Educated Guess:
Define the Conditions That Must be Present for the Educated Guess to be Correct:
Test to See if the Conditions Necessary to Validate the Guess are Present:

Analyze Data:
Implement Findings:

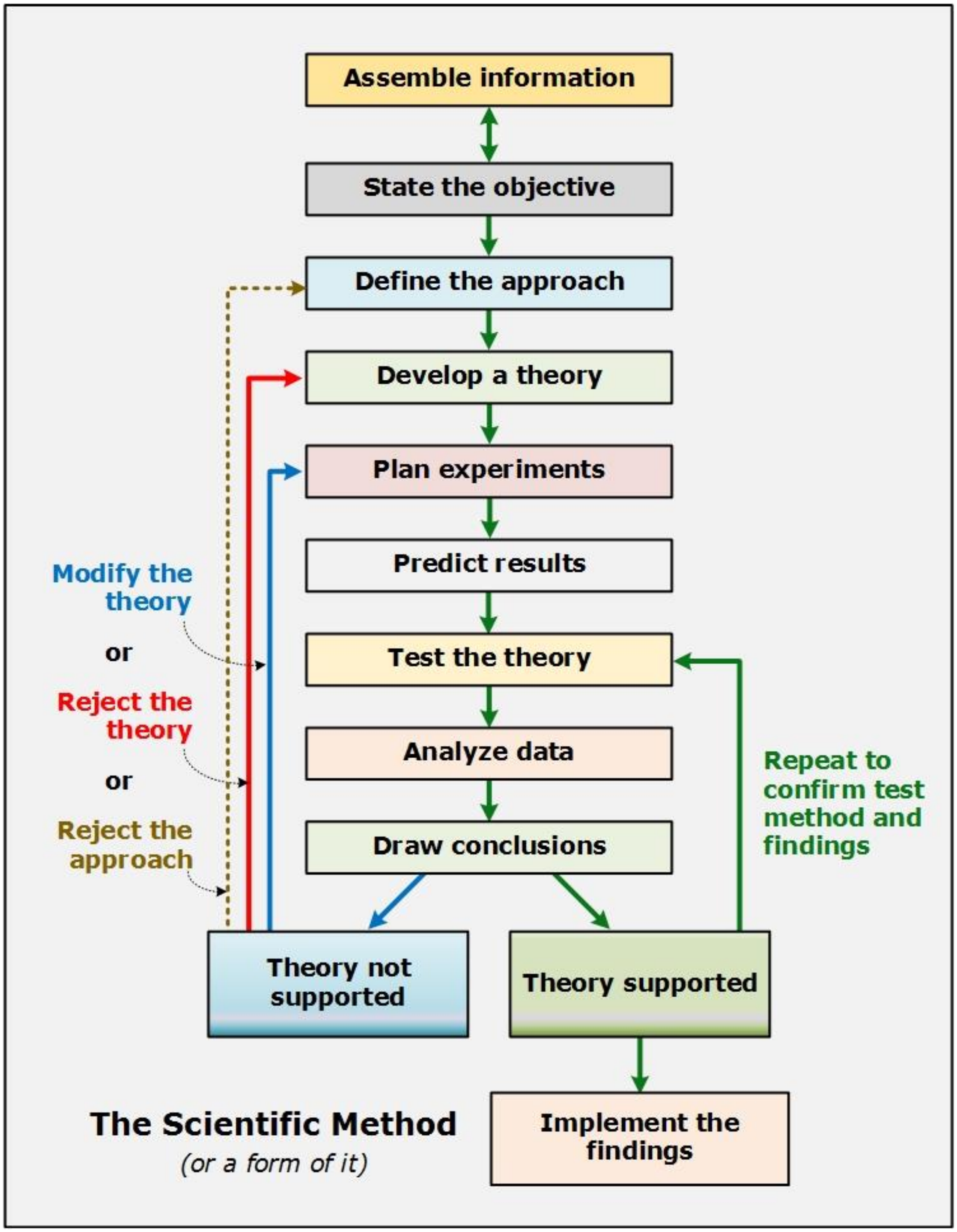
Attachment 3 to the Course Manual

"How?" Special Study Form

Directed Assistance Module 9

Special Studies at the Water Treatment Plant

The Special Study Process Using the Scientific Method



Special Study Format and Elements

Special Study Topic: Identify the name of the special study and briefly describe why the study is being conducted (i.e., one to two sentences).

Assemble Information:

Assemble a complete set of information on the plant status to ensure issues related to reliability of instruments and equipment is not an issue.

Assemble information related to the issue at hand. Focus study on a specific activity.

State the objective of the special study:

Explain the purpose of the study (i.e., treatment processes which you hope to improve and the degree to which it must be improved).

Define the approach <u>to solving the problem</u> that you will evaluate with the special study:

Explain the treatment mechanism by which you hope to improve water quality (i.e., treatment processes or chain of treatment which you hope to improve).

Develop a theory (or theories) you will evaluate with the special study:

Describe the elements and or parameters in the treatment process you are going to experiment with to evaluate potential improvements (ideas).

If practical, develop multiple theories and prioritize them for evaluation in turn. Document the theories, including the reason you think they are relevant to the issue at hand.

Plan experiments:

Determine whether any background data is needed before initiating the study. Include assembling a baseline of current conditions if you have not already assembled this information in a previous step

Use existing test procedure SOPs, if appropriate (i.e., jar test procedures, drawdown test procedures, timed settling test procedures, etc.).

Define the sequence of evaluations, the theories to be tested, and the order in which the test parameters will be adjusted to evaluate the theory (i.e., processes and equipment involved).

Describe resources required (i.e., staff, sampling, and testing).

Involve plant staff in development (operations, maintenance, and laboratory).

In test planning, be sure to adjust only one parameter at a time.

Predict results:

You developed your theories based on the perceived benefit of understanding the impact adjusting a parameter would have: describe the type and degree of impact the adjustments are expected to have. Describe expected results from the study.

Describe how the data will be presented to support the hypothesis.

Define measures of success for the study.

Also, define the test results that would show the theory to be invalidated and enumerate those as well.

Test the theory (theories):

Test the theories one at a time using consistent procedures from one series of tests to the next.

Document the time, parameter adjusted, and the results of each test.

Repeat the tests if there is any question about the validity of the test.

Analyze Data:

Compare test results to predicted results.

Assemble a test summary, tables, and or charts, as necessary to reveal the importance of test findings.

Draw Conclusions:

Conclude: the theory was validated, the theory was invalidated, or more evaluation must be performed.

Conclusions should be based on test results and analyses, not personal preference.

Implement Findings:

To be completed at the end of the study.

Document changes to current plant procedures, based on study results.

(Intentionally left blank)

Special Study Topic:
Assemble Information:
State the objective of the special study:
Define the approach <u>to solving the problem</u> that you will evaluate with the special study:
Develop a theory (or theories) you will evaluate with the special study:
Plan experiments:

Predict results:
Test the theory (theories):
Analyze Data:

Draw Conclusions:
Implement Findings: